A Systems Analysis and Design Tool for Product Design

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ABSTRACT

In the past ten years, system decomposition has been used by product designers to analyze complex products. Good product design practice calls for system level design to occur before detailed design begins. The end result of the system design process is the product architecture. Once the functional architecture of the product is developed, then individual components can be mapped to it.

System decomposition has been shown to be a very effective *analysis* tool; however, practical interactive tools currently do not exist that allow designers and engineers to use system decomposition as a *design* tool. There is a need for the development of a tool that can help design teams create the product or system architecture as they design the product and product family evolution. The purpose of this research is to create a new design tool, and show how it can be applied to a very popular consumer product, the Kodak one-time-use family of cameras.

This research is focused on creating an easy–to–use visualization tool for systems analysis and design. An examination of current visual diagram methods to describe product functions has been studied by applying the Kodak cameras to each method and detailing the benefits and drawbacks of the visualization. Effective visual communication techniques have been applied to the problem so that the design tool is not graphically complex. The ultimate goal is to create interactive software that will assist designers in creating more logical designs. The tool will help designers create new products and product families more efficiently in cost and time, thus leading to greater productivity, and more logical, sustainable designs.

DEDICATION

To my mother who continually inspires me to live outside the box.

ACKNOWLEDGEMENTS

I would like to thank my research advisor, Dr. Blaine Lilly, for the opportunity to be engaged in undergraduate research. I would also like to thank him for being instrumental in critiquing current methods and my designs, instructing a most valuable product design course, and serving on my thesis defense committee. My thanks also go out to Dr. Carolina Gill for serving on my thesis defense committee and her interests in applying the project towards industrial design. Additionally, I am grateful for Dr. James Schmiedeler's critiques of my research presentations and his encouragement.

I would also like to express my sincere gratitude to other members of this interdisciplinary research group who have been very helpful along the way. I would like to thank Mercé Graell-Colas for being exceptionally instrumental in the outcome of the design tool by evaluating designs for an easy-to-use visualization and giving me a crash course on Adobe Illustrator. Additionally, I am thankful for Vignesh Sachidanandam for comparing some current design methods with me which further showed how subjective certain standard methods are.

I would like to thank my family, especially my mother and sister, for their love and support. I am very grateful for my friends and roommates for their encouragement and understanding. I would also like extend my sincere thanks to Theresa Vonder Haar for her laughter and encouragement throughout college.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

BACKGROUND

Systems engineering as a discipline had its origins in the aerospace industry as engineers confronted the task of managing complex systems. NASA created many of the tools and techniques used in systems engineering for use in the Apollo Program and the International Space Station. One of the primary tools that NASA uses to make complex systems more understandable is the functional decomposition method, in which systems are broken down by functions into sub–systems, each sub–system is further decomposed into sub–sub–systems, and so on. The process is repeated until the very basic functions of the system are defined, along with all the connections between them. Flows of mass, energy, and information are mapped, and unintended connections between system components are noted [7].

SYSTEM DESIGN AND PRODUCT ARCHITECTURE

In the past ten years, system decomposition has been used by product designers to analyze complex products. Good product design practice calls for system level design to occur before detailed design begins. The end result of system design process is the *product architecture*. System design establishes the major functions and sub-functions that the system must perform to be successful and specifies the relationships between the functions. The system functions are broken down layer by layer, from the top, until the level of the basic functions is reached. A visual representation can be seen in Figure 1. A single function of the functional decomposition chart can be viewed in Figure 2. This figure shows the three flows of mass, information, and energy, flowing into the system. The outputs from the system are the desired output of the function and noise which is an unwanted output which can exist in many forms such as heat, vibration, dust, sound, etc. The function can then be broken down into sub-functions which can be seen in Figure 3 and the energy, mass, and information can be mapped throughout the functions of the system. Once the functional architecture of the product is developed, then individual components can be mapped to it [5].

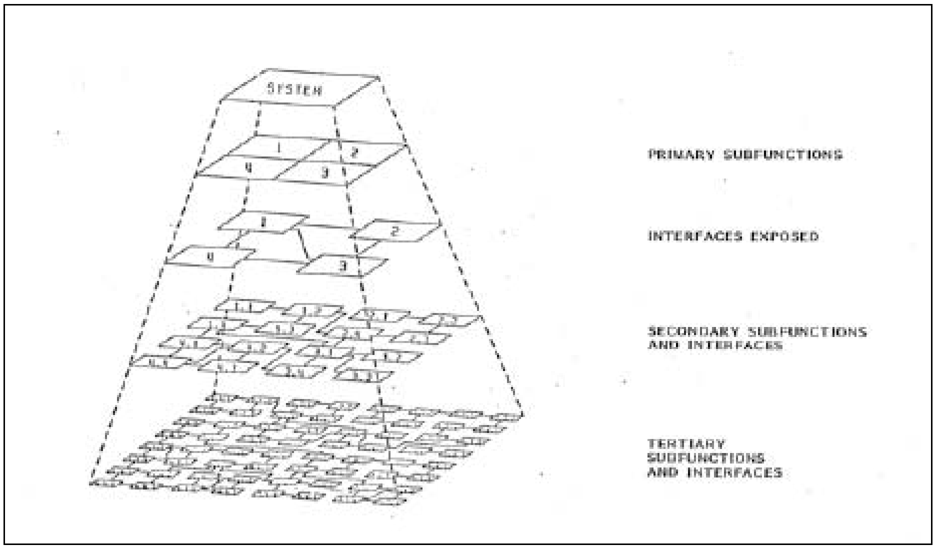


Figure 1: Functional Decomposition [7]

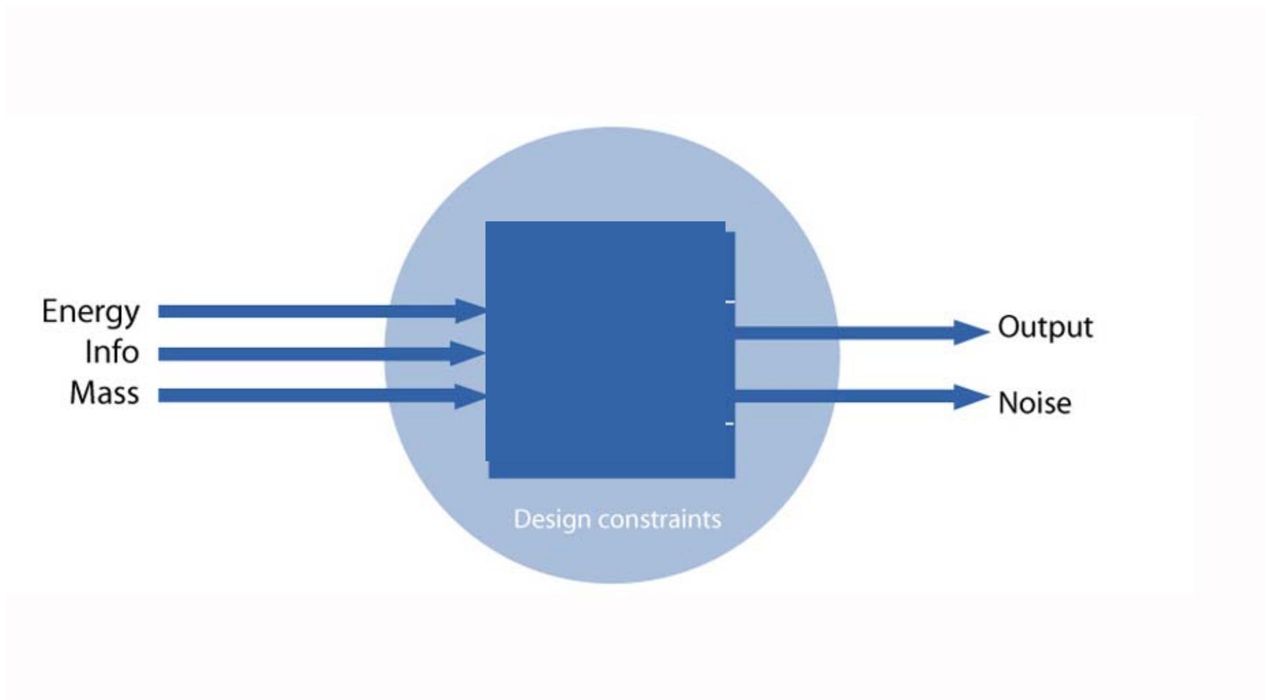


Figure 2: Single Function of Functional Decomposition Chart [7]

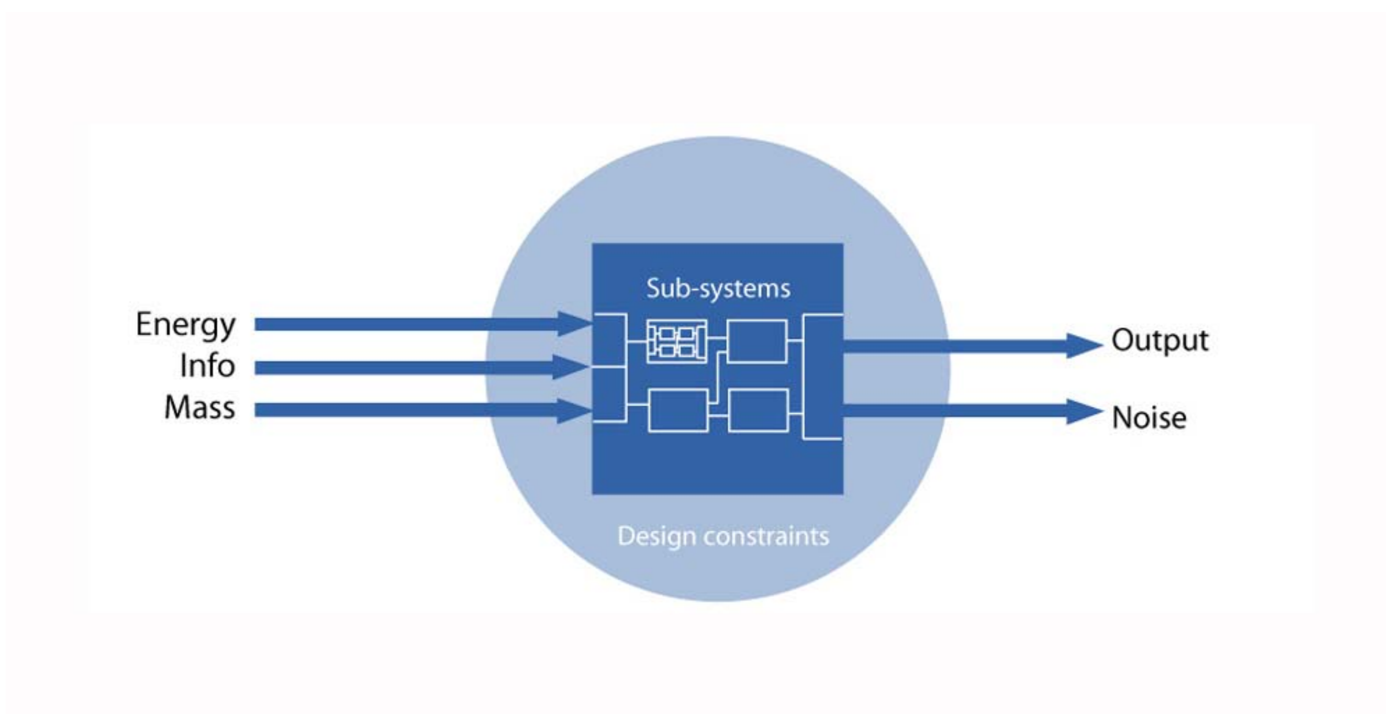


Figure 3: Single Function of Functional Decomposition Chart Broken into Sub-Systems [7]

Products can be described as both functional and physical elements. Ulrich and Eppinger define the functional elements of a product as “the individual operations and transformations that contribute to the overall performance of the product” [6]. Functional system elements take the form of actions and not things. They can be represented as verbs acting on nouns [8]. Usually, functional elements are described in a visual diagram before a certain component or technology is mapped to it [6]. An example of a functional element is “transfer force to actuator” or “store ink.” Notice the physical specifics of how this action is to be performed is not yet detailed. Conversely, physical system elements of a product are things that have form and mass. They can consist of single components or are grouped into chunks that perform the functional elements. Chunks are defined as a grouping of components that operate as one unit [6]. An example of a chunk is a fan on a system that consists of many components such as the blades, bearings, hub, etc. and the fan is implemented into a larger system.

System connections can be either intended or incidental. Connections that have been intentionally designed to have specific mass, information, and energy flows through the system are intended connections. They have been specifically designed to produce a desired outcome of the system. Incidental connections usually result from design oversights and can cause problems such as heat, vibration, etc. throughout the system. A visual representation of intentional and incidental connections is depicted in Figure 4. Good product design entails designing intended connections while minimizing unwanted incidental connections throughout the system design process [8].

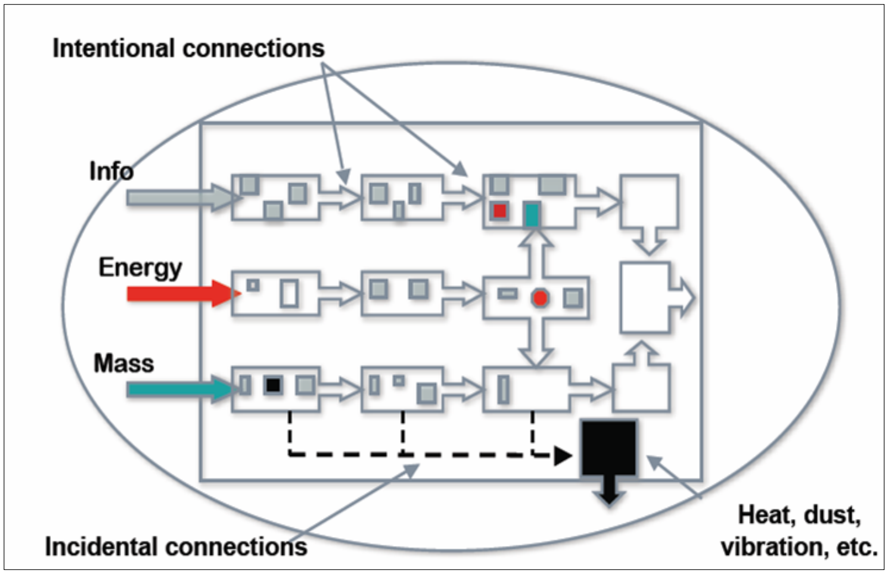


Figure 4: Mapping Physical and Functional Connections in a System [8]

Modularity and integration define the extremes of product architectures. Modular architectures result when a component (or group of components) is mapped to a single function. This means that that particular function can easily be upgraded or repaired by replacing a single component; on the other hand, modular systems tend to be rather bulky and heavy. This type of architecture typically allows for easier assembly, disassembly, upgrade, and repair, because the functional boundaries are well defined. Modular architectures also facilitate standardization across product platforms, which offer significant advantages in adaptability and product evolution. Design changes can be made very easily because one chunk or component can be modified without having a large effect on other chunks of the product. An example of a modular architecture is a desktop computer where components can easily be replaced. While it is often thought that modular products are more easily adaptable, actually modularity is expensive in terms of mass and volume: consider the difference in size between a desktop and a laptop computer that do essentially the same functions [6].

Conversely, in an integral architecture each component typically performs many functions. Integrated product architectures are the result of mapping many functions to single components, or spreading a function out across many components. These systems tend to be high performance, because of the reduction in weight and volume, but are very hard to upgrade, disassemble, evolve, or repair. Modifications to an integral architecture may be difficult and require an extensive redesign to the entire product. This type of architecture is designed with high performance in mind and usually has fewer parts. Additionally, there may be more incidental connections in an integrated architecture because the interactions between chunks are not as well defined. An example of an integrated architecture is the Apple Powerbook, where the aluminum case is not just a case, but is also a heat sink. Most products are a combination of both types of architecture, but can be viewed as predominantly modular or integral [6].

DESIGN FOR…

The modularity or integration of a product's architecture is usually based on the importance of designing for variety, standardization of components, product change, performance, manufacturability, and sustainability and resilience [6]. Depending on the product, one or more of these factors are important design considerations and affect the overall architecture of the product and the evolution of the product family.

…VARIETY

The architecture of a product can be designed to offer a wide or minimal product variety. Depending on market demand, there can be a range of models of a particular product wanted. How fast the firm can develop these models is important to producing a range of products. Products with modular architectures are easier to design for product variety without imposing major changes on manufacturing [6, 10].

…STANDARDIZATION OF COMPONENTS

By standardizing components, the same component or chunk can be used in several products. Therefore, if a component or chunk performs the same function across many products, it would be best to design the chunk as the same in each product instead of doing a redesign of the same part for each product. The firm is then able to manufacture the chunk in larger volumes which leads to a lower cost and can increase the quality of the chunk [6].

…PRODUCT CHANGE

Depending on the design of the chunks in the architecture, this can either impede or facilitate product change. As discussed previously, a modular architecture allows for changes to be made easily to certain functional elements of the product without changing the other chunks. "A modular architecture allows the firm to minimize the physical changes required to achieve a functional change" [6]. Conversely, an integrated architecture is more difficult to change a part of the product without redesigning a significant amount of architecture because the chunks are highly integrated [6].

Ulrich and Eppinger define several motives for product change. As user needs or technology facilitates change, an *upgrade* to the product is necessary. Another motive for product change is to facilitate the use of *add-ons* which are additional components that can be added to a base unit. Longer lived products tend to change with *adaptation* to be used in different environments. Additionally, replacements of components that deteriorate because of *wear* allows for an extended life of the product. *Consumption* is another important consideration when some products require a component to be replenished after it has been consumed. The *flexibility in use* of a product allows the user to configure a product to have different capabilities depending on the use of the product at that instant. Lastly, designing for reuse allows the designers to create a new product by changing a few functional elements while maintaining the rest of the previous model [6]. This can be especially important for keeping cost lower in designing for manufacturing.

…MANUFACTURABILITY

Designing for manufacturing is very important throughout the design process. The architecture of a product has a large impact on producing each chunk at a low cost and in a timely manner. There are many design for manufacturing strategies that vary depending on the type of product. One design for manufacturing strategy is to reduce the part count of a product so it can be assembled easier. This can be done through component integration, but as discussed previously, component integration is not always beneficial especially when designing for product change [6]. Design for manufacturing is taken into consideration as the product is designed and evolves.

…PERFORMANCE

The product's performance is how well it performs the designed functions. Usually characteristics that define the product's performance are "speed, efficiency, life, accuracy, and noise" [6]. Performance metrics typically measure the product performance characteristics as a 'per unit mass' or 'per unit volume'. For example, a measure of performance is not just the product's 'strength' but is its 'strength per unit pound'. Integral architectures usually are designed with performance in mind and the product usually has a size, shape, or mass constraint. A functional architecture eliminates redundancy in the product because several functions are implemented on one component which then allows the product to be more compact. Additionally, materials can be minimized which can lessen manufacturing costs [6].

…SUSTAINABILITY AND RESILIENCE

The idea of sustainable design has become a major theme for engineers in this decade. The combination of rising populations, shrinking resources, global warming, and declining quality of life in many regions of the world is creating growing interest in our ability to design and produce products that are sustainable over many years [3]. What exactly does 'sustainable design' mean? The director of OSU's Center for Resilience, Dr. Joseph Fiksel, defines a sustainable *society* as '…one that continues to satisfy the current needs of its population without compromising the quality of life for future generations.' He further defines a sustainable *product* as '…one that continues, possibly with design modifications, to meet the needs of its producers and customers'; however, he also notes that a single product by itself cannot be considered sustainable, unless it is constantly evolving consecutively with the world around it [1].

Previous work on sustainable design has concentrated on minimizing environmental impact by applying recyclable materials and using energy resourcefully. Recently, many designers and engineers have begun to look to ecology for new insights into sustainability and creating sustainable products. One of the key ideas in ecology is the concept of *resilience*, which ecologists define differently than engineers. *Engineering resilience* is essentially a synonym for *robustness,* which is usually identified as how quickly a system can return to its equilibrium state after being perturbed. More interesting for product designers is *ecological resilience,* which is a measure of how far from equilibrium a system can move before it changes into another, completely new, equilibrium state [1]. The two types of resilience are shown graphically in Figure 5. Truly sustainable products and product families should be created to be resilient in the ecological sense. Resilient products are designed so that they are readily adaptable and can evolve quickly as market conditions change.

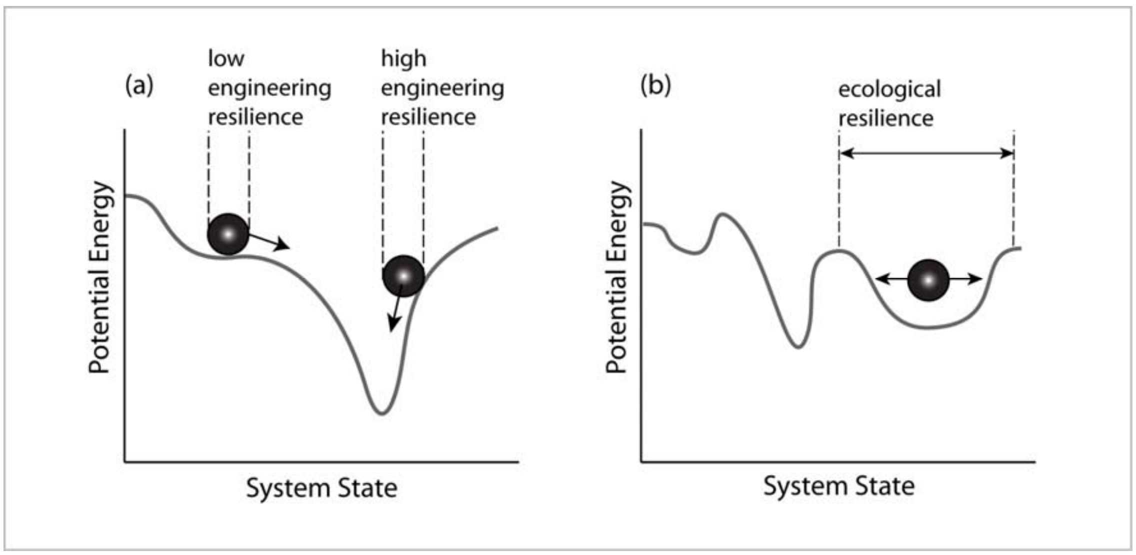


Figure 5: Engineering and Ecological Resilience [2]

Remanufacturing has also become a trend in various future-thinking corporations. The companies are reclaiming products after they have been used in their life cycle. After reclaiming, the product usually gets disassembled and parts are remanufactured and reused. The man hours put in to remanufacture the product are worth it in terms of cost, materials, and time. The remanufactured products must be designed for disassembly which may add costs upfront, but will have much greater returns. Some companies have engineers who specifically look at products that are being designed and how they can improve the life of each part so that when the product gets remanufactured, the parts will have a longer life-cycle. Remanufacturing can lead to more sustainable and environmentally friendly products due to the lack of waste generated [9].

DESIGNING PRODUCT ARCHITECTURE

The product architecture begins to be defined during the development of the product concept. "Sketches, function diagrams, and early prototypes of the concept development phase" begin defining the product's architecture [6]. Depending on if the product is an improvement on an existing product or if it is an entirely new product, the product architecture can evolve differently [6]. The importance of designing for variety, standardization of components, product change, performance, manufacturability, and sustainability and resilience will greatly affect the product's architecture, but there is not a method that allows the designer to consider these factors in a clear and concise way. There are many approaches to designing a product's architecture including system decomposition charts, but there is not one consistent method that allows users to easily design new products and redesign existing products.

MOTIVATION

Currently, very effective design tools for analyzing system architectures do not exist other than system decomposition charts [5]. System decomposition has been shown to be a very effective *analysis* tool; however, practical interactive tools currently do not exist that allow designers and engineers to use system decomposition as a *design* tool. There is a need for the development of a tool that can help design teams create the product or system architecture as they design the product and product family evolution. A major part of this research is to develop better graphic tools for displaying the complexity of product architectures, so that designers and engineers will assemble product families in ways that will facilitate product evolution rather than impede it. There are even a myriad of ways to depict the visual representations of describing product architectures which one can see by the differences of Figures 1-5. The purpose of this research is to create a new design tool, and show how it can be applied to a very popular consumer product, the Kodak one-time-use family of cameras.

This research is focused on creating an easy–to–use visualization tool for systems analysis and design. An examination of current visual diagram methods to describe product functions has been studied by applying the Kodak cameras to each method and detailing the benefits and drawbacks of the visualization. Effective visual communication techniques have been applied to the problem so that the design tool is not graphically complex. The ultimate goal is to create interactive software that will assist designers in creating more logical designs. The tool will help designers create new products and product families more efficiently in cost and time, thus leading to greater productivity, and more logical, sustainable designs.

RESEARCH APPROACH

In order to create a new visualization tool to aid designers and engineers in developing products, first a case study of a product will be performed. The product architecture will be analyzed as well as how each component is mapped to the functions. This analysis will be important not only for an in-depth understanding of how the product operates, but will also be used to evaluate current methods and other visualization techniques. Therefore, each visualization or method will be analyzed using the same product so the pros and cons can be compared. The details of the case study and analysis of methods will be described in chapters two and three, respectively. Based on this research, a new, easy to use visualization tool will be developed for product design in chapter four.

CHAPTER 2: KODAK CAMERA CASE STUDY

One objective of this thesis is to take a very successful product family that has evolved over the past twenty years—the Kodak one-time-use cameras—and look very closely at the system architecture to analyze the components of the camera and their functions. This case study will be beneficial when detailing current methods of characterizing product architectures. Kodak cameras were chosen for the case study because of the product's reputation for high quality even though it is a 'disposable camera' sold at a very low cost. As the consumer uses the product, when the camera is turned in for developing the film, the camera is then sent back to Kodak. Some camera models are even 90% recyclable. This allows Kodak to have a very local retail price point around eight dollars which maintains a profit in the changing marketplace even in the age of digital photography.

Kodak cameras have many mechanical parts that operate in a sequence to expose the film at just the right time to capture an image. Within this sequence of events, there is motion of film through the camera as well as information relayed through the circuit board. The product is not a simple device such as a screwdriver but is not as extremely complicated as a turbine engine. The camera was chosen for this case study because it is manageable by one person to take apart and scrutinize the interactions between the components and yet is not a simple object.

The Kodak camera analyzed in the study is a standard one-time-use camera with the option of a flash. In the Appendix, photos of each component of the camera are documented, as well as the various functions of each component and the location of the function. An example of a component is shown below of the counter wheel in Figure 6. Table 1 below shows the number of functions for the twenty components of the camera. There are a range of functions associated with each component. The frame, for example, contains 53 functions and the front cover contains 27 functions, whereas the lens and the metering spring only contain two functions. From this camera analysis, it is important to thoroughly understand the interactions between the components and their functions in order to analyze the current methods and how their advantages and disadvantages in portraying the Kodak camera.

1. Manufacturing hole.
2. Hole maintains plane on which the counter wheel turns. Hole is stabilized on frame.
3. Numbers show visual cues of how many pictures are left.
4. Gear teeth turned by cam allow rotations of numbers.
5. Manufacturing.

Figure 6: Functions of Counter Wheel in Kodak Camera

Table 1: Number of Functions for Each Kodak Camera Component

Component	Number of Functions
Frame	53
Front Cover	27
Rear Cover	25
Keeper Plate	19
Lens Retainer	17
Viewfinder	10
Metering Lever	9
Spool	9
Cam	8
HEL (High Energy Lever)	8
Shutter	6
Counter Wheel	5
Thumbwheel	5
Flash Board Assembly	5
HEL Spring	4
Contact	4
Sprocket	3
Shutter Spring	3
Metering Spring	2
Lens	2

Documenting the functions of each component sheds light into the modularity and integration of the camera. Some components, such as the frame, are highly integrated with other components which can be seen by the amount of functions associated with the component. Other components, such as the lens have only two functions. This component can be considered more modular because if Kodak wanted to implement a new lens into the camera, this piece could be changed with ease. Additionally, the lens is recycled into viewfinders by Kodak because the polycarbonate viewfinder does not need to have perfect quality like the lens. Having this piece be modular allows for easier disassembly during the recycling process.

After documenting the functions of the components of the camera, there is a need for a design and analysis tool that defines the product architecture. Ideally, this tool should be able to contain functional system elements and physical system elements. System connections should be documented as well as flows of information, mass, and energy. The user of the tool should be able to “design for…” something specific such as manufacturing, performance, recyclability, etc. and ideally be able to design for all of these criteria. The tool needs to also be used to show modifications in potential next generations of a product. Overall, the findings of the case study show that the design and analysis tool must be adaptable to meet the user’s needs and be easily understood. A variety of current analysis methods will be analyzed and the benefits and drawbacks will be noted on the path to creating a new product design tool.

CHAPTER 3: ANALYSIS OF CURRENT METHODS

ULRICH AND EPPINGER: FOUR STEP METHOD TO ESTABLISH PRODUCT ARCHITECTURE

Ulrich and Eppinger detail a four-step method to structure how decisions are made to establish the product architecture. The four steps are illustrated throughout using an example of a DeskJet printer. The steps are: "

1. Create a schematic of the product.
2. Cluster the elements of the schematic.
3. Create a rough geometric layout.
4. Identify the fundamental and incidental interactions."

A schematic is a "diagram representing the team's understanding of the constituent elements of a product" defined by Ulrich and Eppinger. The schematic is detailed after the concept development phase, where some elements are physical concepts while the rest are described functionally. Flows of forces or energy, material, and signals are mapped throughout the system. An example of a schematic from Ulrich and Eppinger can be seen in Figure 7. Every detail is not represented in the schematic, and Ulrich and Eppinger's rule of thumb is to aim for less than 30 elements in a schematic in order to keep the complexity within reason to establish the product architecture easier.

In step two, the elements of the schematic are to be clustered into chunks. This is up to the team designing the product, and there are innumerable alternatives for clustering the elements of a schematic. Factors to consider when arranging into chunks are function sharing, the capabilities of the vendors, designing for variety, localizing change within the product, clustering similar technologies, designing for standardizing of components, and distances between interactions [6]. Figure 8 shows a proposed architecture for the DeskJet printer that is taken from Ulrich and Eppinger.

Step three involves creating a rough geometric layout of the product. This can be created in two or three dimensions using various methods such as sketches, computer software, or physical models. The geometric layout allows the design team to consider the geometric interfaces between the chunks and to work out dimensions. Industrial designers should also be included in this step when there are human interfaces and aesthetic considerations. An example provided by Ulrich and Eppinger of the DeskJet's geometric layout can be seen in Figure 9.

Lastly, the intended and incidental interactions are to be identified. The purpose of this is when working in a design team where the chunks get divided among team members, it is important to coordinate how each chunk interacts among others. Figure 10 shows an interaction graph which maps the incidental interactions [6].

Ulrich and Eppinger's four step method has some benefits and drawbacks. Overall, showing the mass, information, and energy flows of the system allows the designers to understand the system as a whole and how interactions occur. Also, detailing how the geometry of the chunks interacts is important and drawing or physically constructing a model is helpful. Additionally, mapping the intended and incidental connections is important, especially if there are multiple people working on multiple parts of a product.

There are, however, drawbacks to this procedure. When drawing the schematic of the product, each schematic will be different depending on the person who creates it. One person might document something functionally while another physically. There is no consistency between what should be documented physically at what design stage. Having less than 30 elements in a schematic seems like an arbitrary number, and what happens when something very large such as an airplane engine is being designed? The team is also supposed to agree on a schematic, which further details the discrepancy between what might and might not be included in the schematic. Since the schematic is what the rest of the steps follow from, it seems that there must be a consistent method regarding exactly what the schematic should entail, beyond simply the agreement of the design team. This would be particularly important if the diagram were to be used in the figure by other teams to develop derivative products. Looking at figures 7 to 10, it can be seen that if a very complex product was attempted to be designed using this method, the visualization would become very graphically complex and most likely confusing. Overall, there needs to be more structure and consistency to the diagrams, that would also allow for the adaptation for complex architectures.

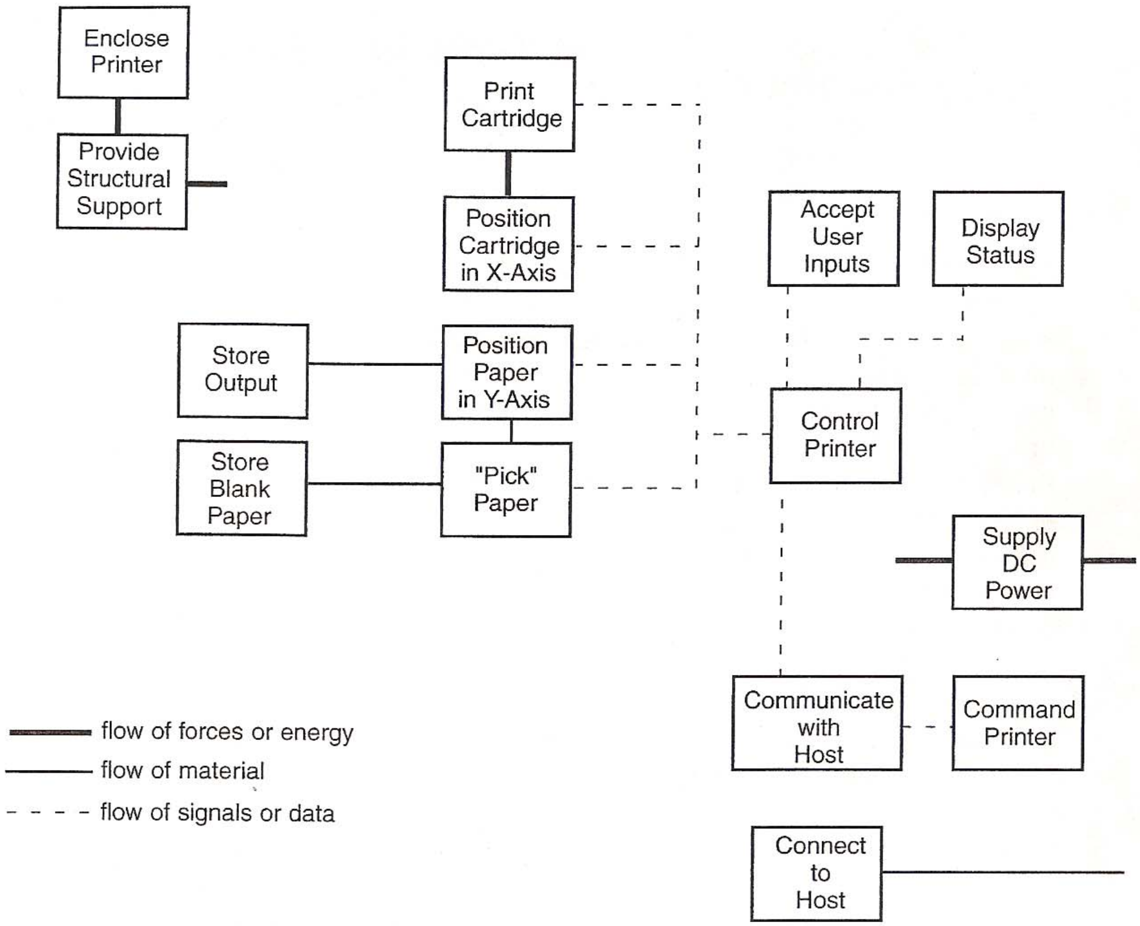


Figure 7: Ulrich and Eppinger's Schematic of a DeskJet Printer [6]

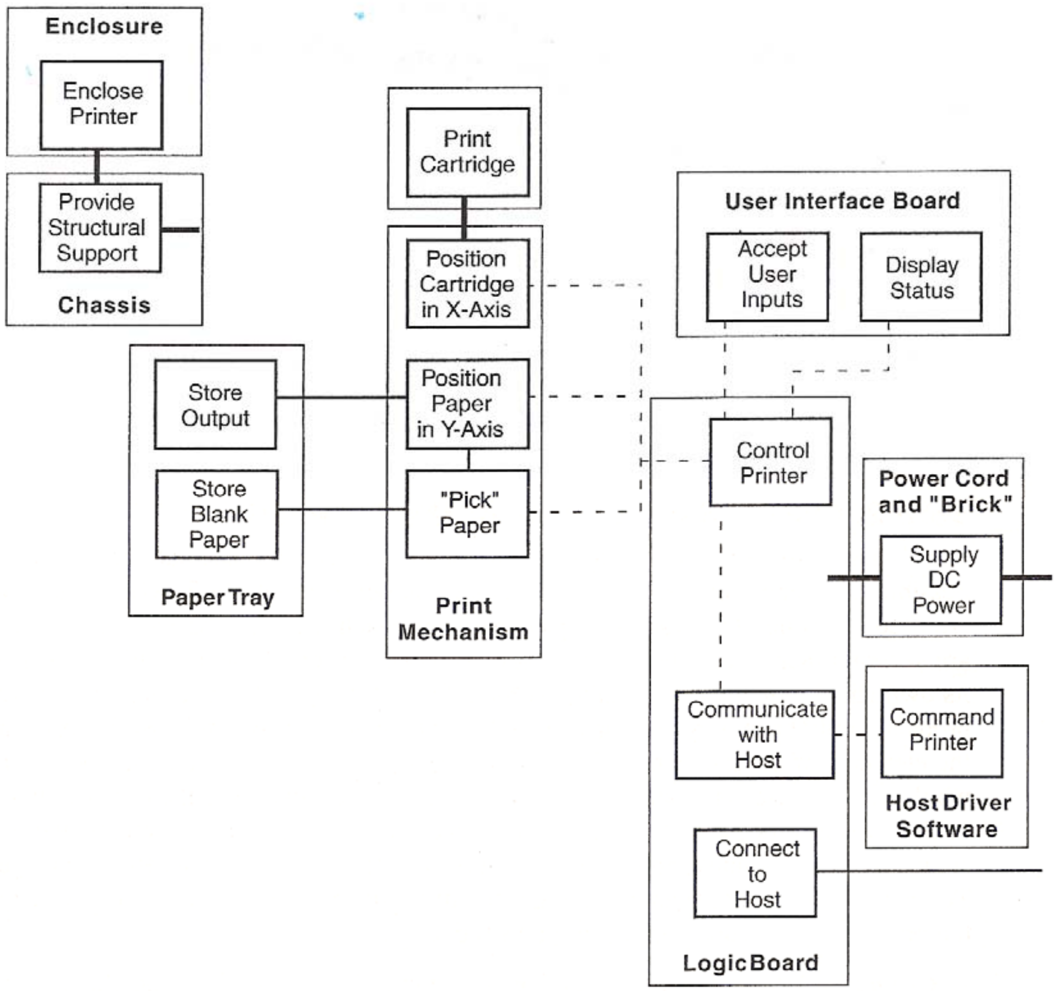
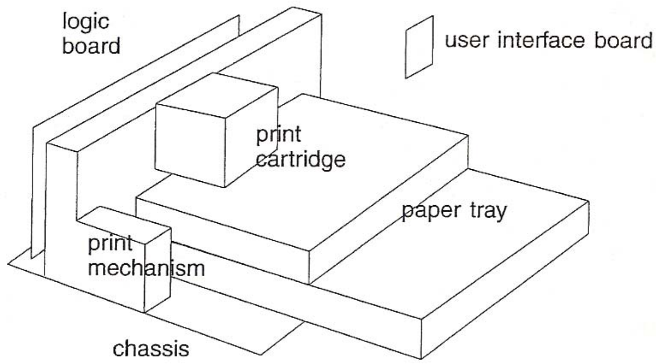


Figure 8: Ulrich and Eppinger's Chunk Clustering in the Schematic [6]



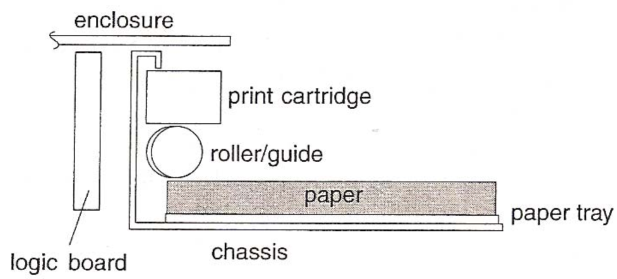


Figure 9: Ulrich and Eppinger's Physical Layout of a DeskJet Printer [6]

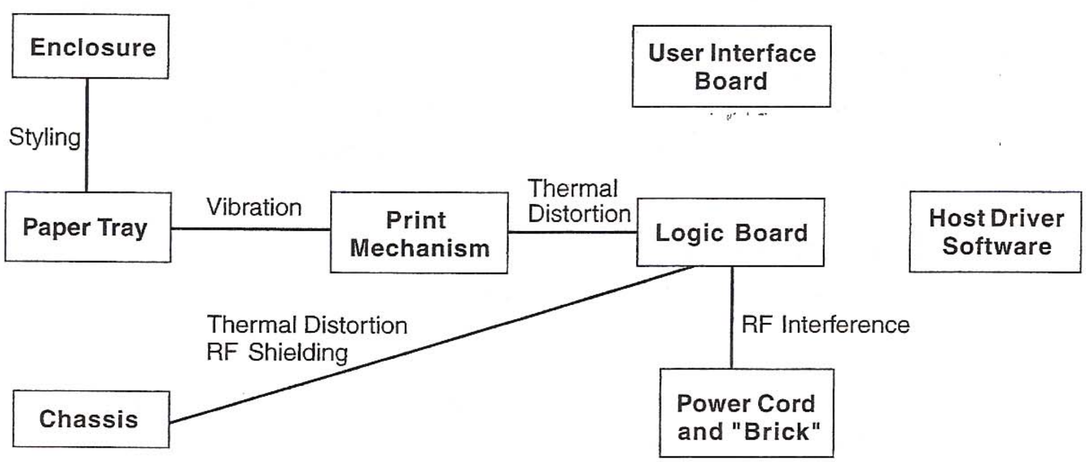


Figure 10: Ulrich and Eppinger's "Incidental Interaction Graph" [6]

FUNCTIONAL BASIS: STONE AND WOOD

Stone and Wood present a consistent design language to be used to describe product functions; they refer to the language as a “functional basis” [11]. The paper details how important a consistent design language is when using functional models and how a universal language does not currently exist. To compare product architectures among a myriad of products, document the design process, compare product functions, and to establish metrics and benchmarks are just some of the ways in which Stone and Wood believe that the functional basis will be beneficial to product designers. Stone and Wood create a design vocabulary and detail the definitions of each word and whether they are a material, energy, or signal flow. An example of a power screwdriver is given using the black box model where the functions get broken down into sub-functions and so on as well as flows of energy, material, and signals are also documented. This example can be seen in Figure 11   [11].

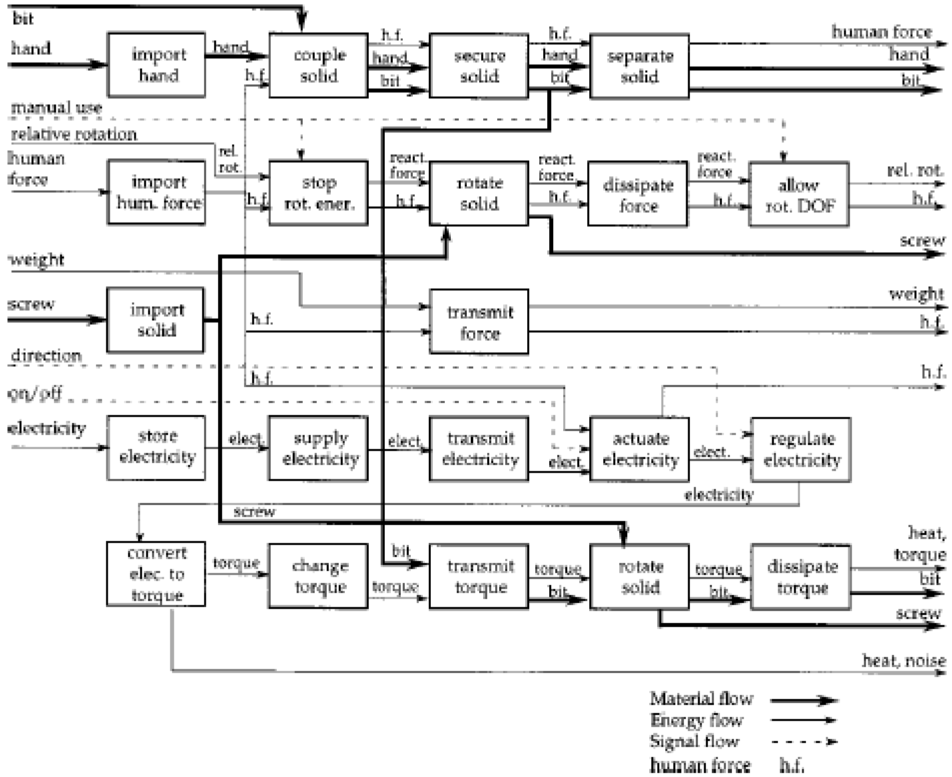


Figure 11: Stone and Wood's Functional Model for a Power Screwdriver [11]

The common design language seems to be a beneficial endeavor if this could be adopted by all product designers alike. The functional models become more understandable with the functional basis terms used; however, the functional model itself is not addressed. As seen in the figure, there is still an extensive amount of lines detailing the flows between the functions. Stone and Wood also document the human force that flows through the system which is an important consideration. A universal functional model using a common design language would be ideal.

DESIGN STRUCTURE MATRIX (DSM)

The Design Structure Matrix is a model used to represent product architecture. Sharman and Yassine assert that DSM is most useful when the product is not complex, and that DSMs are not widely understood by all disciplines. DSM models consist of the physical relationships between components and their interactions in order to characterize the product's architecture. This is accomplished through a square matrix structure where the row and the columns represent each component. A node is marked when components interact with each other. A large "X" marked shows a strong relationship between the elements, and a small "x" shows a weak relationship [13]. Alternatively, a weighting scheme can be used to describe the spatial relationships between the components. When reading a component in a row, one can visually see which elements that component provides to. Similarly, when reading a component in a column, one can visually see which elements that component depends on [14]. See Figure 12 for a representation of the DSM.

When analyzing a DSM, the objective is to cluster elements together that are "mutually exclusive or minimally interacting" [13]. These clusters are useful when developing a product to be modular or integral as well as when designing a product with components that need to have spatial separation or adjacency for the functionality of the product. A physical schematic is also drawn which represents flows of mass, information, energy, and spatial constraints between components. Multiple conceptual architecture diagrams can be conceived using the physical schematic and the physical DSM. The conceptual architecture diagrams have modules determined from clustering the DSM [13]. Sharman and Yassine further detail Molecular Diagrams which are three dimensional drawings used to characterize very complex architectures. Size, color, and density of the molecules are determined by the creator as well as weights of the lines and arrow conventions to describe the elements [13].

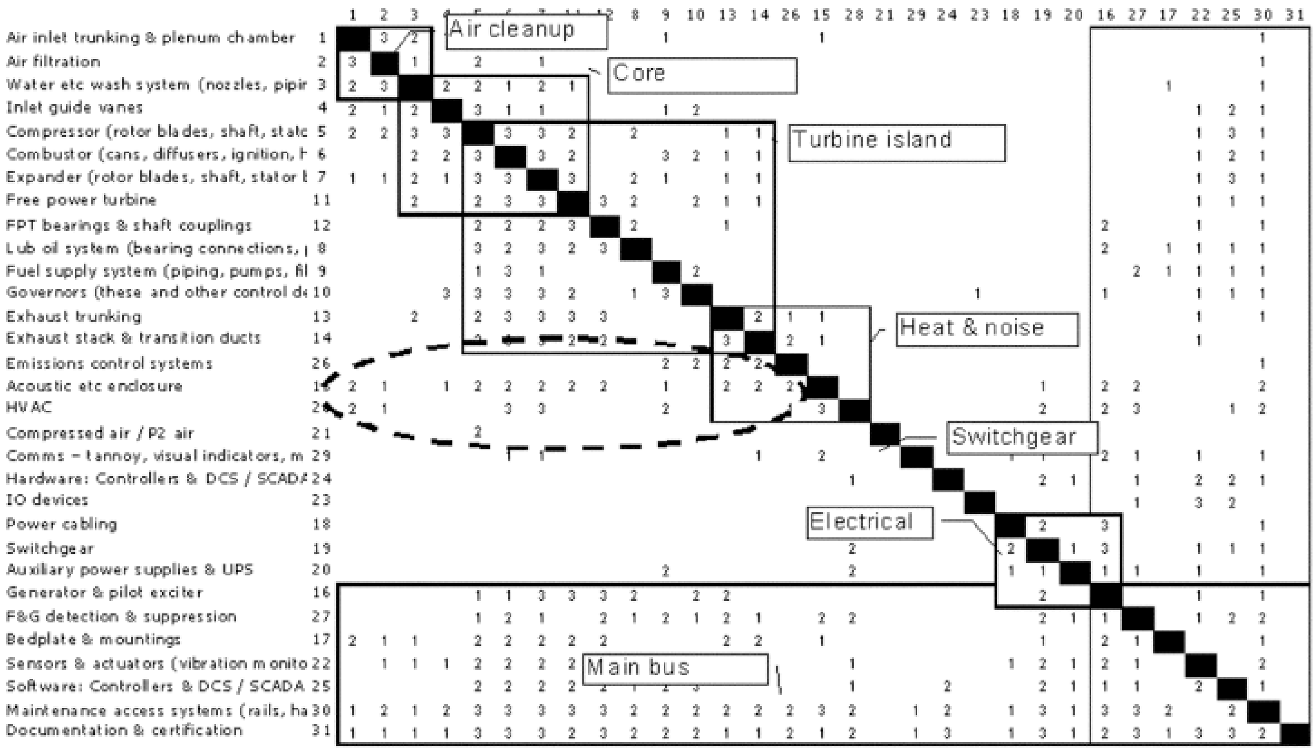


Figure 12: “A Physical DSM of a Gas Turbine” [13]

There are various advantages and disadvantages of using DSM and molecular diagrams. Sharman and Yassine detail several advantages of the DSM that include the DSM being a good beginning point for noting product information and in addition to being useful in examining noncomplex products or focusing on a highly specific part of a product’s architecture. Disadvantages of using the DSM include the inability to compare DSM diagrams between different designs of the product as well as being unable to analyze complex or large systems [13]. Sharman and Yassine state that molecular diagrams are useful in conveying ideas to non-technical people but have disadvantages that include a lack of detail which makes it difficult to technically analyze a product [13].

When applying the DSM and physical connection diagram to the Kodak camera, several advantages and disadvantages of the method were noted. On both diagrams, the flows of mass, information, and energy are hard to define and put into perspective for the whole motion of the system. Information in the camera flows both to and from the user, and from components to the film, which are difficult to document on the matrix. The camera contains twenty components and the DSM seems too complex to analyze for these components. Another disadvantage of this method is that it is only valid for evaluating existing products. There is difficulty in giving a rating on strong versus weak connections in the system which makes the overall DSM method too subjective for a standard method. The DSM also does allow the display of more complex interactions. For example, in the camera, space must be provided so that the light from the LED must pass through open space in the camera from the flashboard to the viewfinder to a hole in the rear cover to the user's eye. Other examples include the button on the keeper plate which must have space allotted by the front cover and rear cover for the button to be pressed. Even simple requirements, such as having a hole in the camera such as that there must be a hole in the front cover for the lens cannot be depicted in the DSM. The DSM is inadequate in showing the motion of the film through the camera and the process taking a picture beginning with the user. The DSM cannot show any of the "design for…" categories, and the user of the model needs to be able to map the constraints in the system. On the other hand, the DSM does show the integration of the components. The physical schematic is beneficial for showing how the camera's components physically interact with each other. The DSM and physical schematic need to be able to be easily understood for complex products and developing products, and the DSM is too subjective for a standard.

		Frame	Front Cover	Rear Cover	Spool	Flash Board	Spring	Shutter	Lens Retainer	Lens	Retainer	Keeper Plate	View Finder	Counter Wheel	Sproket	Cam	Metering Spring	Metering Lever	Thumbwheel	HEL	HEL Spring
Frame			P	P	P	P		P	P			P	P	P	P	P	P	P	P	P	P
Front Cover	I			P		P															
Rear Cover	I		P		P																
Spool																					
Flash Board	I						P	P													
Spring																					
Shutter																					
Lens Retainer								P		P	P										
Lens																					
Retainer										P											
Keeper Plate														P		P			P	P	
View Finder	I																				
Counter Wheel																		P			
Sproket																P					
Cam														P				P		P	
Metering Spring																		P			
Metering Lever																			P		
Thumbwheel																					
HEL																					P
HEL Spring								P													

Figure 13: Physical Dependency Structure Matrix of Kodak Camera (I=Information, P=Physical Connection)

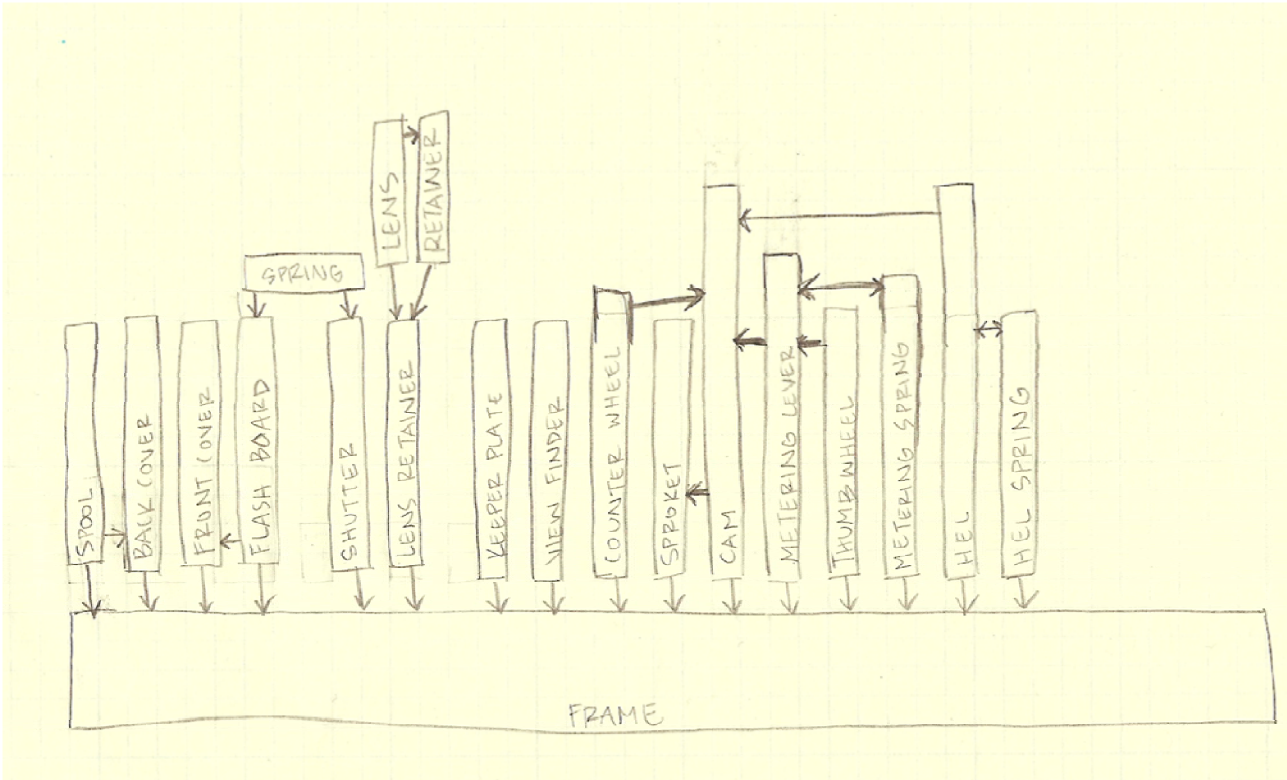


Figure 14: Physical Connections of Kodak Camera

DESIGN FOR VARIETY: MARTIN AND ISHII

Martin and Ishii describe a method that helps companies develop a robust product platform architecture. The method is used to reduce design effort and the time to market for subsequent product generations. The overall concept is that of “specification flows” that are to be used throughout product development that are based on wanting to design for variety. Two types of variety are considered, ‘special variety’ which is variety within a current product, and ‘generational variety’ which is variety across generations of the product.

Martin and Ishii detail two types of indexes to measure a product’s architecture. One index is the Generational Variety Index (GVI) which is defined as “an indicator of the amount of redesign required for a component to meet the future market requirements.” The second index is the Coupling Index (CI) which “indicates the strength of the coupling between the components of a product. The stronger the coupling between components, the more likely a change in one will require a change in another.”

The method for determining the GVI is a complicated, seven step process which has been taken directly from Martin and Ishii and is outlined below. The descriptions have been paraphrased and the figures are taken directly from Martin and Ishii’s example of a DeskJet printer.

GVI Step 1: Determine market and desired life of product platform

The life of the product platform along with current and future market predictions is important to note before beginning the process. This can be seen in Table 2.

Table 2: Martin and Ishii: GVI Step 1: Example Market and Introduction Dates [10]

Market	Description	Introduction Date
	Development Start	*Jun-99*
Current	Home	Dec-99
Future 1	Business (Low Volume)	Jun-00
Future 2	Home (Lower Cost)	Feb-01
Future 3	Business (Improved Perf.)	Nov-01

GVI Step 2: Create a Quality Function Deployment matrix

A modified Quality Function Deployment (QFD) structure in two phases is used at this point of the GVI. The structure comes from previous work from Hauser and Clausing. QFD Phase one is a matrix that details customer needs and how they relate to engineering metrics. The 'X' indicates a relationship among the two factors being compared. QFD Phase two is a matrix that maps the engineering metrics from Phase one to actual physical components used in the design of the product. Figure 15 show Martin and Ishii's examples of QFD Phase I and II for a DeskJet printer.

Customer Requirements \ Engineering Metrics (EM)	Pages per minute (PPM)	Dots per inch (DPI)	Decibels (dB)	Footprint (sq in)	MTBF (hrs)	Unit cost ($)
Prints fast	X					
Good image quality		X				
Low noise			X			
Compact				X		
Reliable					X	
Low cost						X

Engineering Metrics \ Components	PCA/Firmware	Print Cartridge	Carriage Motor Assembly	Input/Output Paper Tray	Feed Motor Assembly
Pages per minute (PPM)	X	X	X	X	X
Dots per inch (DPI)	X	X	X		X
Decibels (dB)		X	X	X	X
Footprint (sq in)	X		X	X	
Reliability (MTBF)	X	X	X	X	X
Unit Cost ($)	X	X	X	X	X

Figure 15: QFD Phase I and II for a DeskJet Printer [10]

GVI Step 3: List expected changes in customer requirements

In this step, a column is added to the QFD Phase 1 matrix which states "Expected range of change over next (insert number from Step 1) years". This column is then evaluated qualitatively as “High/Medium/Low.” The development team can then visually see how customer needs are predicted to change. See Figure 16.

Customer Requirements	Pages per minute (PPM)	Dots per inch (DPI)	Decibels (dB)	Footprint (sq in)	MTBF (hrs)	Unit cost ($)	Expected range of change over next 2 years
Prints fast	X						H
Good image quality		X					M
Low noise			X				L
Compact				X			L
Reliable					X		M
Low cost						X	H

Figure 16: “QFD Phase I with Expected Change in Customer requirements” [10]

GVI Step 4: Estimate engineering metric target values

The engineering metric target values are then added to the overall matrix for each time frame that the product platform will be developed from the Table in step 1 and Figure 17 shows the diagram.

Customer Requirements	Pages per minute (PPM)	Dots per inch (DPI)	Decibels (dB)	Footprint (sq in)	MTBF (hrs)	Unit cost ($)	Expected range of change over next 2 years
Prints fast	X						H
Good image quality		X					M
Low noise			X				L
Compact				X			L
Reliable					X		M
Low cost						X	H
EM Target Values (EMTV)							
Current Market	6	600	42	216	1500	100	
Future Market 1	8	600	48	216	2000	125	
Future Market 2	6	600	39	216	1500	75	
Future Market 3	12	1200	42	150	2500	100	

Figure 17: "QFD Phase 1 with EM Target Values Added" [10]

GVI Step 5: Calculate normalized target value matrix

Martin and Ishii state in this step that, “This information is used to graphically display the changes for the target values. This step is skipped for this shorted DFV description.” The reader is unsure what this means.

GVI Step 6: Create GVI matrix

Here the design team is to determine on a 9/6/3/1 rating system to estimate the cost of changing components in order to meet engineering metric objectives. The rating system can be seen in Table 3 which shows the cost as a percentage to the original design costs. An example of the GVI matrix can be seen in Figure 18.

Table 3: "GVI Matrix Rating System" [10]

Rating	Description
9	Requires major redesign of the component (>50% of initial redesign costs)
6	Requires partial redesign of component (<50%)
3	Requires numerous, simple changes (<30%)
1	Requires few, minor changes (<15%)
0	No changes required

	Components				
Engineering Metrics	PCA/Firmware	Print Cartridge	Carriage Sub-system	Input/Output Paper Tray	Feed Sub-System
Pages per minute (PPM)	6	9	3		3
Dots per inch (DPI)	6	9	3		1
Decibels (dB)		1	3		1
Footprint (sq in)	1		1	3	1
Reliability (MTBF)	3	3	1	1	1
Unit cost ($)	3	3	1	1	1

Figure 18: “Phase II Matrix with GVI Input” [10]

GVI Step 7: Calculate GVI

The GVI is then calculated for each component by summing each of the columns of the GVI matrix from step 6. This can be seen in Figure 19.

Engineering Metrics	PCA/Firmware	Print Cartridge	Carriage Sub-system	Input/Output Paper Tray	Feed Sub-System
Pages per minute (PPM)	6	9	3		3
Dots per inch (DPI)	6	9	3		1
Decibels (dB)		1	3		1
Footprint (sq in)	1		1	3	1
Reliability (MTBF)	3	3	1	1	1
Unit cost ($)	3	3	1	1	1
GVI	19	25	12	5	8

Figure 19: "GVI Calculation" [10]

The method for determining the CI is another six step process. “Specification flows” are mapped between components and are important design information to detail to designers.

CI Step 1: Develop basic physical layout for the product

The basic geometric layout of the product and technologies used should be known in order to develop the CI.

CI Step 2: Draw control volume around components

A control volume is defined as “a boundary around a system indicating the flows into and out of that system.” Martin and Ishii state that the control volumes drawn should be roughly the same level of complexity meaning to avoid something like having one component as a bolt and a pump as another.

CI Step 3: List specification flows required between components

The specifications that are received from and supplied to each control volume are to be listed for each control volume. This should then be put into another matrix and an example can be seen in Figure 20.

	Components supplying specifications			
Components receiving specifications	PCA / Firmware	Sensitivity	Print Cartridge	Sensitivity
PCA / Firmware			Resistance	9
			# of nozzles	3
			Nozzle pitch	3
			# of inks	3
			Firing rate	3
			Ink viscosity	3
			Drying time	3
Print Cartridge	Voltage	6		
	Firmware	1		

Figure 20: "Partial CI Matrix of Specification Flows" [10]

CI Step 4: Build a graphical representation of the specification flows

Building a graphical representation of the flows from step 3 is considered optional, but helps in visualizing the flows. An example can be seen in Figure 21.

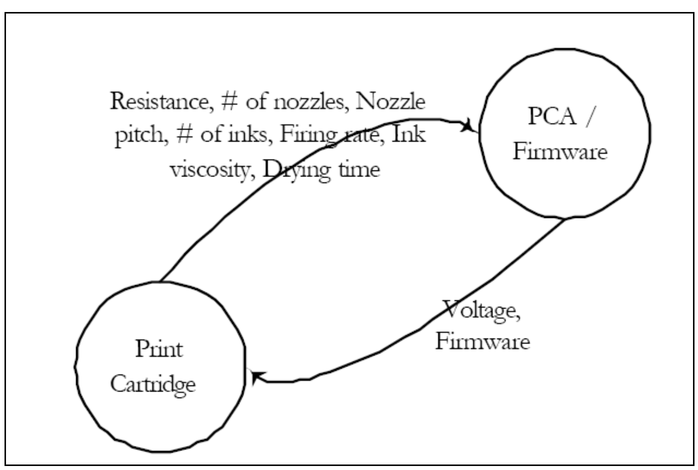


Figure 21: "Graphical Representation of Specification Flows" [10]

CI Step 5: Estimate sensitivity of components to changes

The sensitivity is then estimated based on how the component can manage change within a specification. The rating system can be seen in Table 4. These values are then added to the matrix from step 3 and an example can be seen in Figure 22.

Table 4: "CI Rating System for Sensitivity of Specifications" [10]

Rating	Description
9	Small change in specification impacts the receiving component (High Sensitivity)
6	Medium High Sensitivity
3	Medium Low Sensitivity
1	Large change in specification impacts the receiving component (Low Sensitivity)
0	No specifications affecting component

	Components supplying specifications					
Components receiving specifications	PCA / Firmware	Sensitivity	Print Cartridge	Sensitivity	Carriage Sub-Assembly	Sensitivity
PCA / Firmware			Resistance	9	Motor speed	3
			# of nozzles	3	Resistance	6
			Nozzle pitch	3	Torque	1
			# of inks	3		
			Firing rate	3		
			Ink viscosity	3		
			Drying time	3		
Print Cartridge	Voltage	6			X dimension	6
	Firmware	1			Y dimension	6
					Z dimension	6
Carriage Sub-Assembly	Voltage	6	Weight	3		
	Firmware	1	X dimension	6		
			Y dimension	6		
			Z dimension	6		

Figure 22: "Partial CI Matrix of Specification Flows Including Sensitivity Ratings" [10]

CI Step 6: Calculate coupling index

Two coupling indexes are calculated from the matrix in step five. The Coupling Index-Supply is the sum of a column which "indicates the strength of the information supplied by that component to other components" and the Coupling Index-Receiving is the sum of a row and is an indication of the strength received. An example can be seen in Figure 23. A graphical representation of the full coupling index can be seen in Figure 24 along with the full matrix in Figure 25.

Components supplying specifications

Components receiving specifications	PCA / Firmware	Sensitivity	Print Cartridge	Sensitivity	Carriage Sub-Assembly	Sensitivity	CI-R
PCA / Firmware			Resistance	9	Motor speed	3	**37**
			# of nozzles	3	Resistance	6	
			Nozzle pitch	3	Torque	1	
			# of inks	3			
			Firing rate	3			
			Ink viscosity	3			
			Drying time	3			
Print Cartridge	Voltage	6			X dimension	6	**25**
	Firmware	1			Y dimension	6	
					Z dimension	6	
Carriage Sub-Assembly	Voltage	6	Weight	3			**28**
	Firmware	1	X dimension	6			
			Y dimension	6			
			Z dimension	6			
CI-S		**14**		**48**		**28**	

Figure 23: "Partial CI Matrix Including CI's" [10]

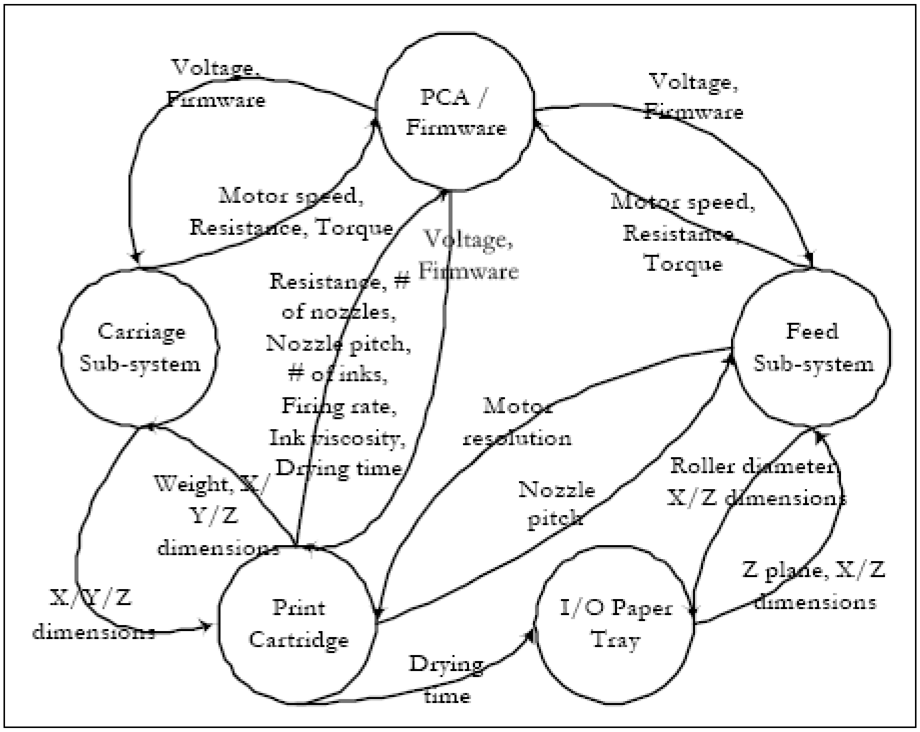


Figure 24: "Graphical Representation of Specification Flows" [10]

Components supplying specifications

Components receiving specifications	PCA / Firmware	Sensitivity	Print Cartridge	Sensitivity	Carriage Sub-Assbly	Sensitivity	I/O Paper Tray	Sensitivity	Feed Sub-Assembly	Sensitivity	CI-R
PCA / Firmware			Resistance # of nozzles pitch # of inks Firing rate Ink viscosity Drying time	9 3 3 3 3 3 3	speed Resistance Torque	3 6 1			Motor speed Resistance Torque	3 6 1	47
Print Cartridge	Voltage Firmware	6 1			dimension dimension dimension	6 6 6			resolution	9	34
Carriage Sub-Assembly	Voltage Firmware	6 1	Weight dimension dimension dimension	3 6 6 6							28
Input / Output Paper Tray			Drying time	3					Roller diameter X dimension Z dimension	9 3 3	18
Feed Sub-Assembly	Voltage Firmware	6 1	pitch	6			Z plane dimension dimension	6 3 3			25
CI - S	21		57		28		12		34		152

Figure 25: "Complete CI Matrix Including CI's" [10]

Overall, the GVI and CI allow designers to understand how change can affect components and the product as a whole. Figure 26 shows the GVI and CI specification flows for the printer example and is to be used to design product architecture. Another four step method detailed by Martin and Ishii begins with generating the GVI and the CI in order to design for variety. The components are then rank ordered by the GVI and the CI values are documented. This is important to show what components are most likely to change throughout the duration of the product platform. Components are then designed as “modularized or standardized” based on the GVI and CI. The team can then begin to develop a product platform that can be helpful in future product generations [10].

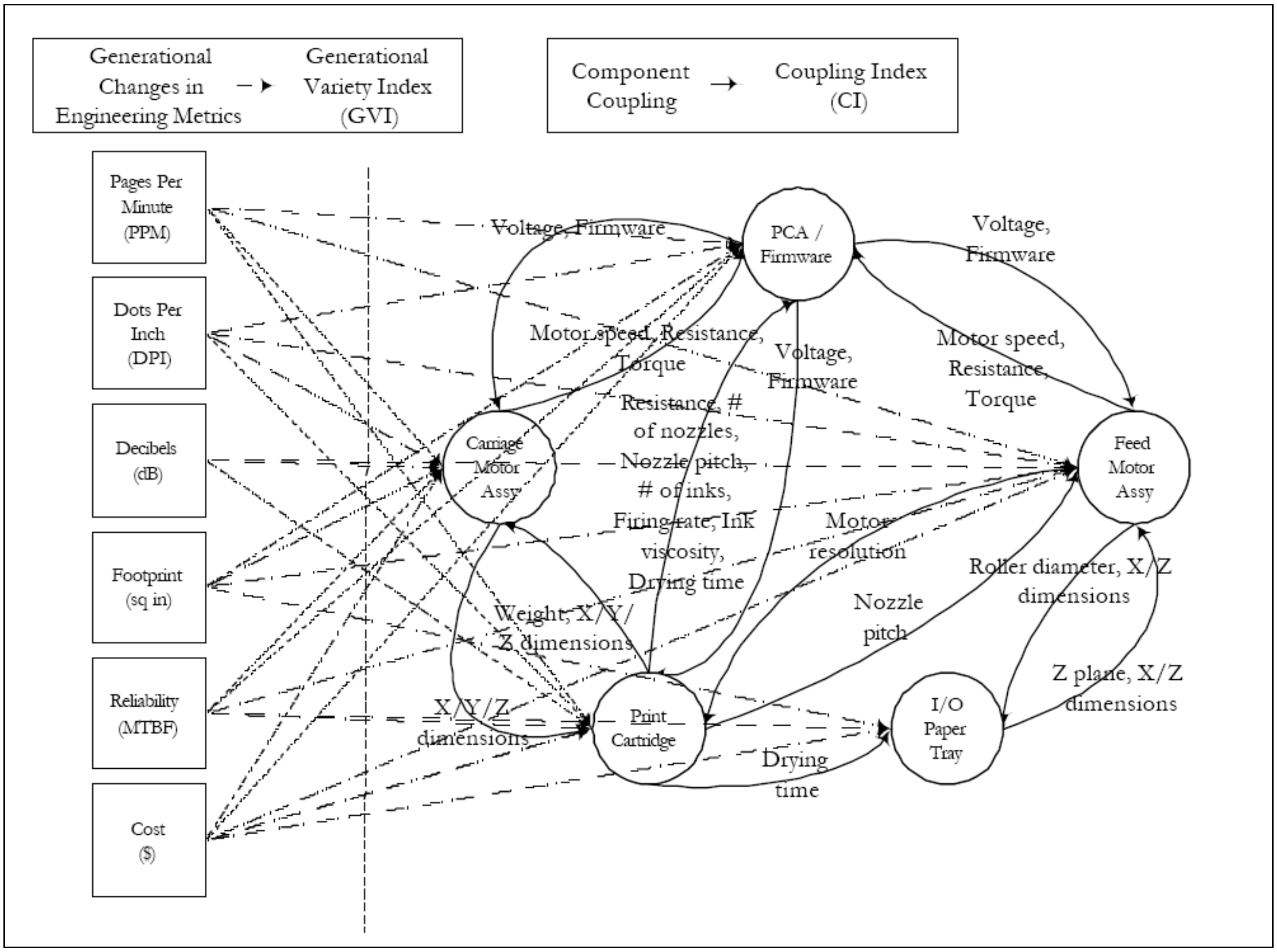


Figure 26: "GVI & CI Specification Flows" [10]

This process seems very long and complicated to have an end result that is just a confusing diagram. The GVI steps are very rigid and structured matrix forms which are typical of engineering diagrams. They make it hard to really grasp what all the numbers and columns mean at once and how this can actually be applied to design subsequent products. Step one in determining the CI seems simple enough to just develop the basic physical layout for the product, but if this is a redesign of a product or developing a new product, this step should have steps within itself on how to design the best geometric layout for a product. This step also ignores flows of mass, energy, and information throughout the system and how to document what's going on internally throughout the functions of the product. The functions of the product are not even mentioned in this method. The numbers used in the matrices are subjective, and even in the simplified version of the DeskJet printer, there is a significant amount of numbers to consider. This method would not be very useful for designing very complex systems or brand new products. Considering the last figure, mapping the engineering metrics to the components seems irrelevant and the entire diagram becomes unreadable due to the excessive amount of lines that exist. This figure especially shows how complicated even the end result of the method is, and the difficulty in using this to design for variety.

THE HOUSE OF QUALITY

The “house of quality” originated in 1972 at Mitsubishi and has been used by many large corporations as a basic design tool. The house of quality reflects consumer opinions and needs and allows engineers, marketing, and manufacturing to work in a multidisciplinary environment. Hauser and Clausing describe the house of quality as a “kind of conceptual map that provides a means for interfunctional planning and communication” [12]. Hauser and Clausing also note that the concept of the house of quality is not difficult to understand, but takes some getting used to. The side of the house consists of consumer attributes that are weighted to show relative importance and always total 100 percent. The top of the house contains engineering characteristics that can have an affect on the customer attributes. This creates a matrix that shows how engineering decisions can affect consumer preferences. The roof shows which engineering characteristics relate to each other, both negatively and positively, so if one feature is changed it shows which other features It affects. Consumer opinions of competitive products can also be added to show how the product stacks up against other products with the consumer attributes. An example of a house of quality can be seen in Figure 27 from Hauser and Clausing [12].

The importance of the house of quality is that it allows interdisciplinary groups to communicate effectively using engineering and consumer parameters. Although this method does not show how to design product architecture, it is a visualization tool that can be adapted for a simple or very complex product.

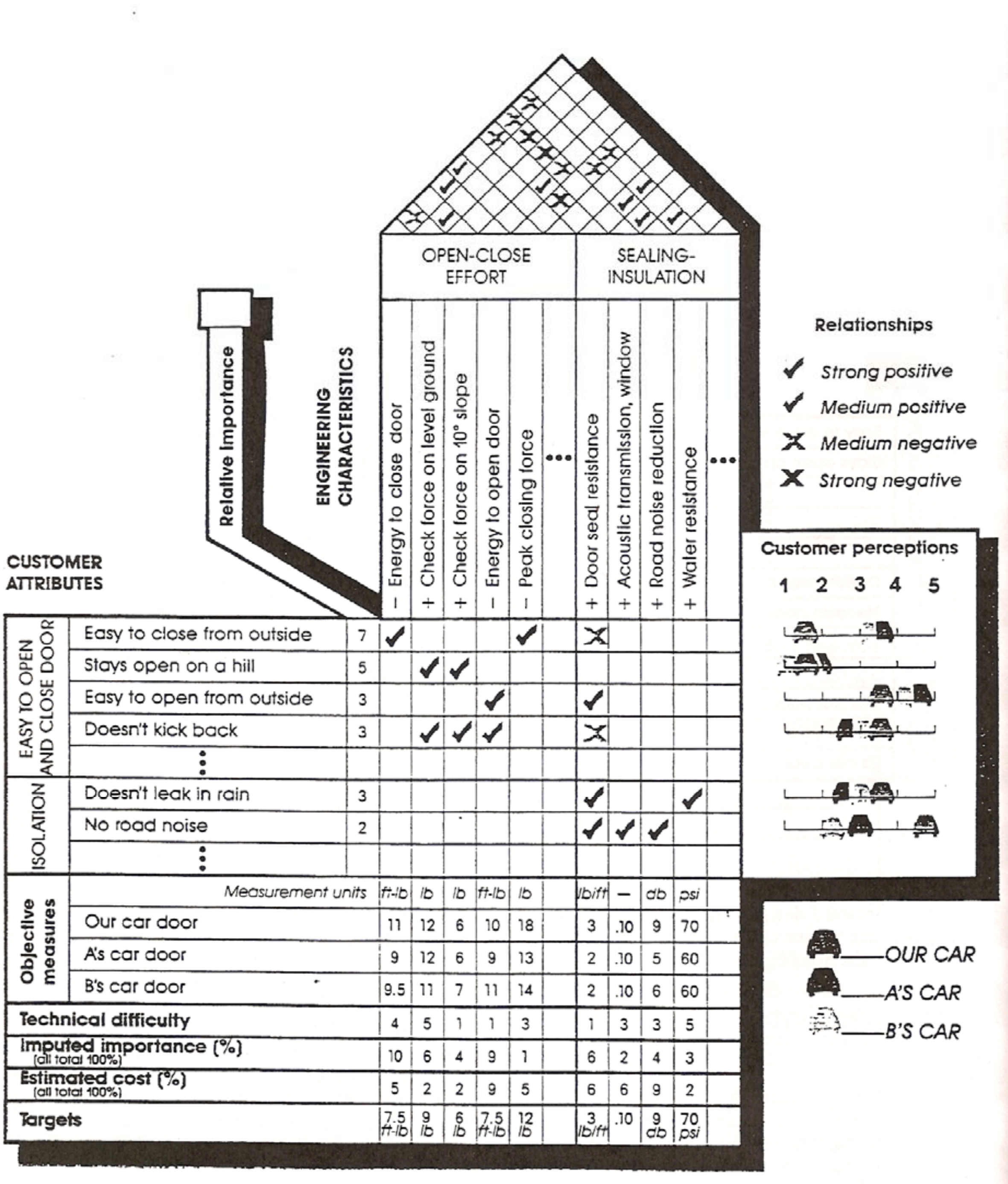


Figure 27: House of Quality Example [12]

KODAK CAMERA PRODUCT ARCHITECTURE

Using the standard black box approach to product architecture drawings, Ed Liu, an undergraduate at Ohio State, has created a flash animation of the functions and components of a Kodak disposable camera. Figure 28 to 30 show screen shots of this flash animation which show the top level, second level, and part of the third level. Looking at the top level, one can see the flows of information, mass, and energy flowing through the overall function of the camera which is to capture and record an image. On the second level, one can see how the overall function gets broken into sub-functions and the mass, information, and energy flowing through the functions. On one of the third levels which is shown in the figure, the “advance film” sub-function is broken into further sub-functions that at this point also incorporate the components of the camera [15].

This approach to a product architecture diagram has benefits and drawbacks. Mass, information, and energy are visually depicted throughout the system. When the user reaches the third level, it is difficult to see how the third level functions interact with each other. The user therefore cannot see the whole picture at once upon reaching the third level. This makes it difficult to analyze the entire product in specific detail. Additionally, a problem in how the diagram is depicted relates to the fact that the boxes are shown in a sequential manner according to when the function takes place in relation to other functions. This is problematic when a new product is being designed and the event sequence is still unknown. The product architecture diagram is beneficial for analyzing existing products, but is not as useful for designing new products. Overall the diagram is visually complex with lines crisscrossing and becomes increasingly complex with a large and intricate product.

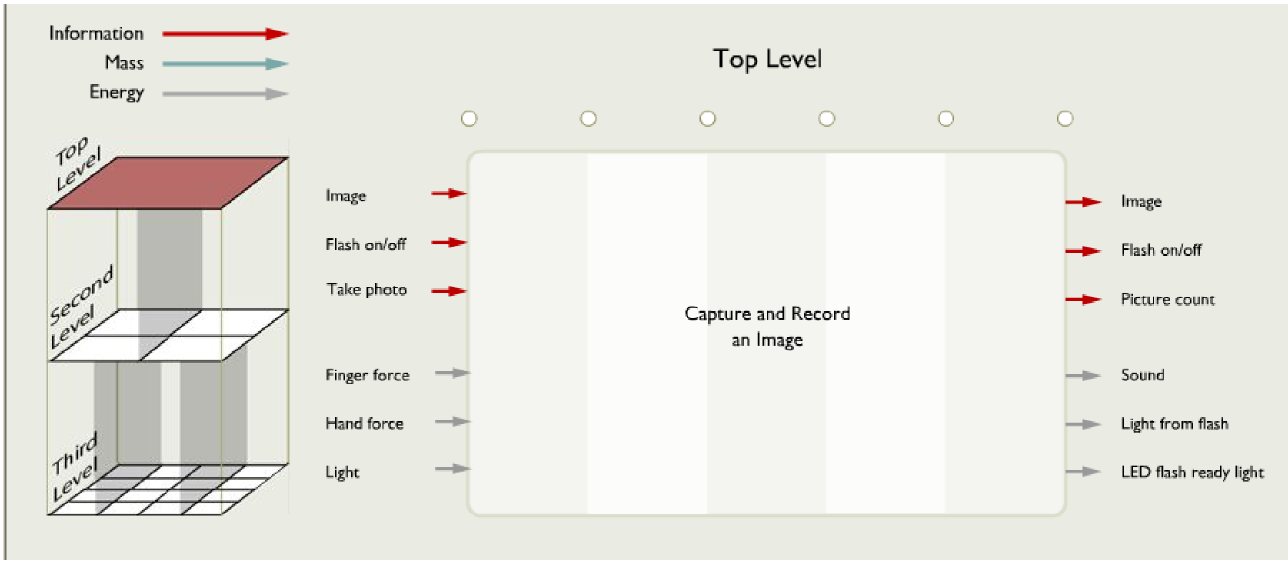


Figure 28: Top Level of Kodak Camera Product Architecture [15]

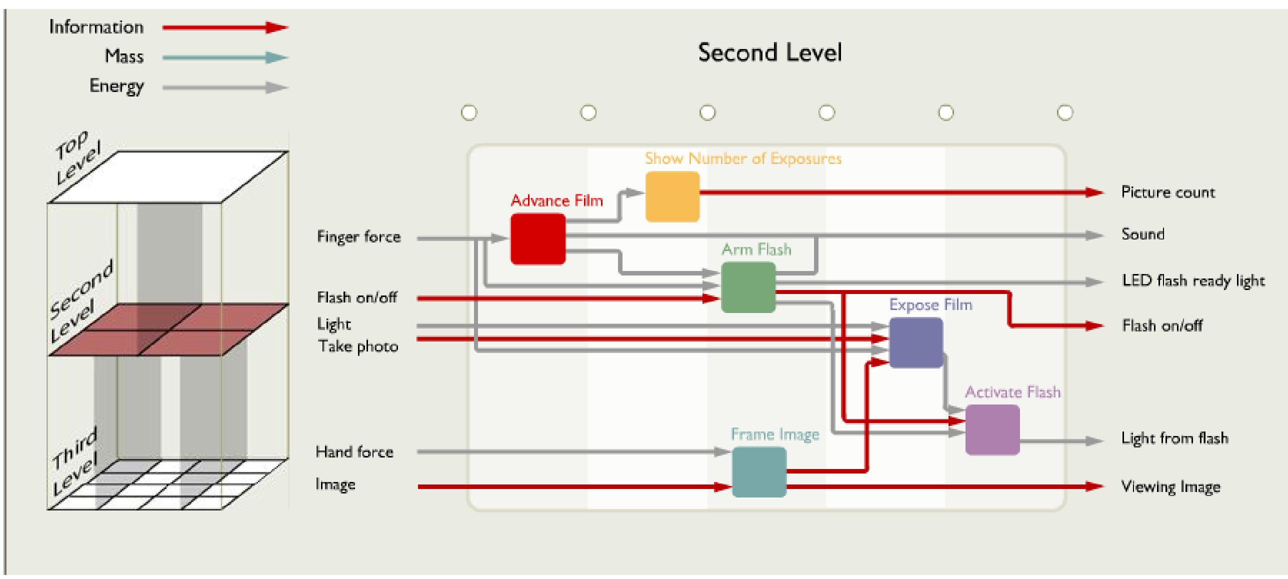


Figure 29: Second Level of Kodak Camera Product Architecture [15]

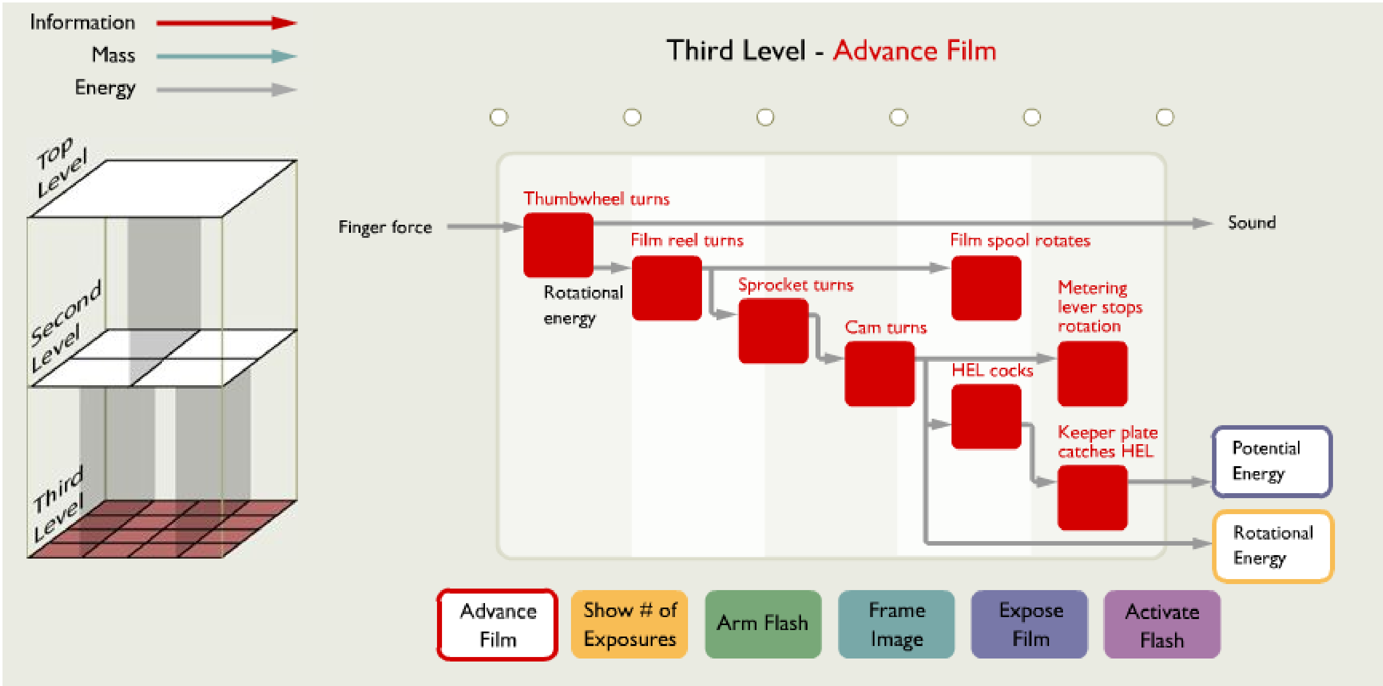


Figure 30: Third Level of Kodak Camera Product Architecture [15]

CHAPTER 4: DEVELOPMENT OF A SYSTEMS ANALYSIS AND DESIGN TOOL

From the Kodak camera case study as well as through a through analysis of current methods, an easy-to-use visualization tool for product design and analysis has been developed from this research. The new systems analysis and design tool is highly adaptable to the users' needs and allows for the user to input the information into the design. The tool can contain as many levels of functions and sub-functions as necessary, maps the flows of mass, information, and energy through the functions, and gives the user the ability to show one level or all the levels at once. The tool is significantly easier to use and easier to read through simple visual conventions which allow all types of designers to use the design tool. Ultimately, the new design tool developed is unique and has the ability to analyze current products and design new products. Figures 31 to 34 show screenshots of the software concept developed through this research using the Kodak camera example.

The top level shows the information and energy flowing through the overall function of the camera which is to capture and record an image. The information flow is shown in blue where the words such as "image" and "picture count" as well as the arrow visually show whether the flow is into or out of the system. This is similar to the energy flow which is shown in orange. Since the current view is of the top level, the top level looks like a three dimensional sphere. The overall software capabilities depicted in the top view are that the user can see the overall product function, colors show the differences in flows, the arrows show mass, information, and energy flows for the overall system, and a simple ‘click’ on the top level will show the sub-functions on the second level.

The second level shows in the information and energy flowing through the sub-functions of the product. The software has the ability to keep the top level in the background so the user is visually aware of what level is being viewed. The second level circles are now highlighted to appear three dimensional and the top level is in the background as a muted grey color. The user can still view the overall flows coming in and out of the top level shown through the use of words and arrows. These flows can now be seen flowing into and out of the sub-functions on the second level. The internal flows of the system can also be seen. These flows can be distinguished from the external flows because of the line styles used. Additionally, the direction of the internal flows can be easily noted because the dot at the end of the lines signifies output to input similarly to a line with an arrow at the end.

Comparing this Figure 32 to Figure 29, one can easily note the simpler design and less complexity of the new diagram. The software would have the capability to ‘click’ and map the flows throughout the system. For example, if the user wanted to see how energy flow of the finger force input flowed through the system, the user would simply click on the input and the flow would be sequentially highlighted throughout the diagram. Similarly, if the user wanted to map all of the energy flows throughout the second level, the user would have the ability to only turn on the energy flows and leave the information and mass flows in the background.

The third level has many similar features to the second level. Whether it be the second, third, fourth, fifth, etc. level, the same features would exist throughout the software. The current level the user is viewing is still highlighted in a three dimensional illustration. The user has the ability to view all the levels at once or just the current level. The user can also view all the circles in the diagram or view only one circle. All flows can be mapped through the functions and sub-functions or the user has the option to view only specific flows. The last level will have physical components mapped to the functional components which are shown here in level three. The user also has the ability to arrange the spheres in chronological order according to timing of the functions within the components. This can then be graphically seen in the diagram. After the user inputs all of the necessary information into the spheres, the software would have the ability to arrange the spheres in a manner to show the best view of the diagram without crisscrossing lines throughout. Basically, the user gets to see what the user wants to see.

With the development of the new design tool, the software would have the capability to facilitate designing for specific categories. If the user wants to design for variety, they have the ability to view the components on the diagram that they would like to change easily for designing for variety and see which functions and sub-functions are potentially connected to the component. The user can design for the standardization of components through a product family through comparing diagrams and grouping like functions into components. When designing for product change, the new software tool would be very instrumental because if there is a component that the designer knows is going to be upgraded, needing repair, has the potential for add-ons, or reuse, the designer can use the diagram to isolate that component and know exactly which functions and components that component will be affecting and be able to design around it. When designing for performance, the designer can have one component do all the functions, or be completely modular and have one component for each function. From the diagrams, the designer can immediately tell between the extremes. Similar concepts can be used for designing for manufacturability or sustainability and resilience.

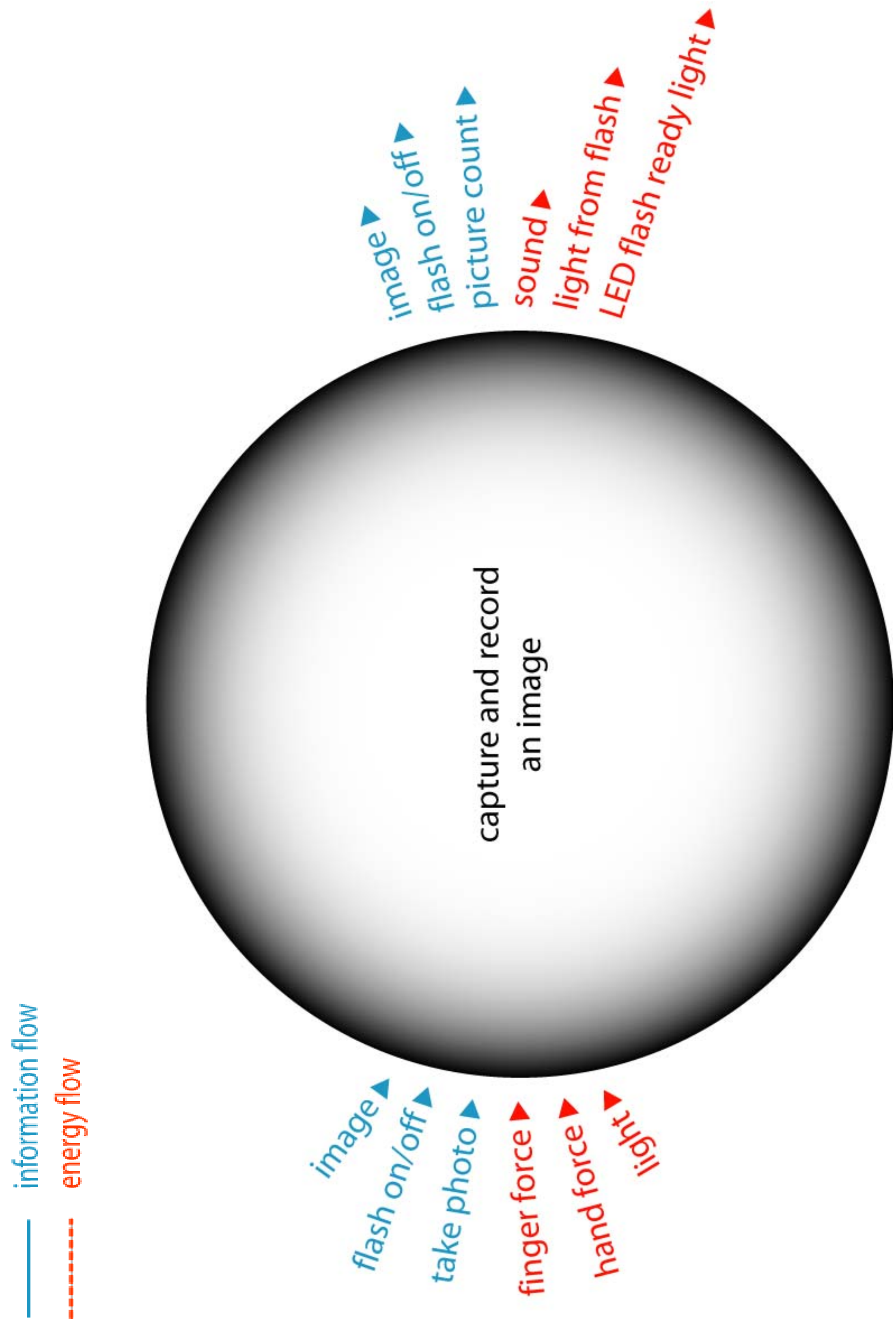


Figure 31: Top Level of Kodak Example of New Graphical Tool

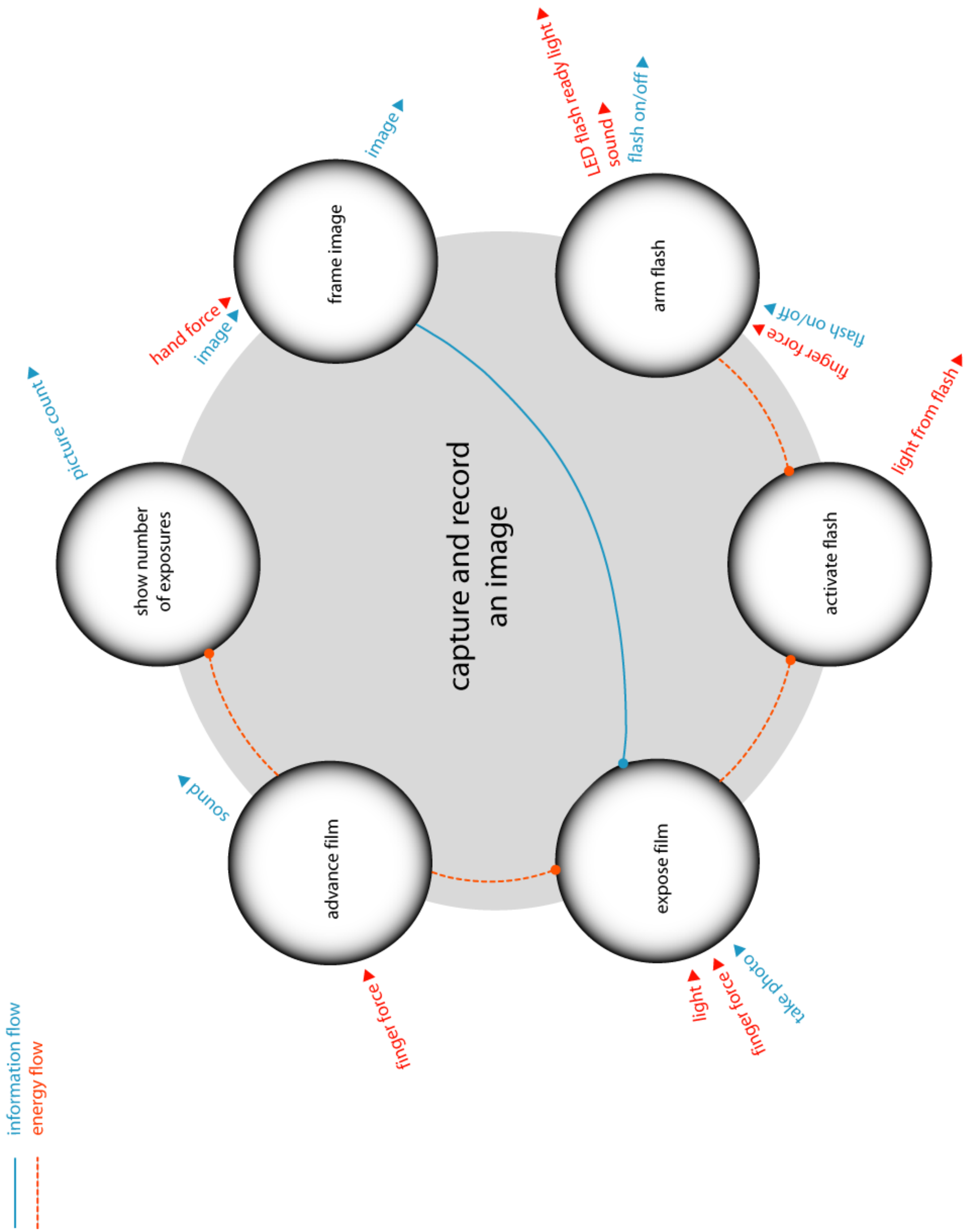


Figure 32: Second Level of Kodak Example of New Graphical Tool

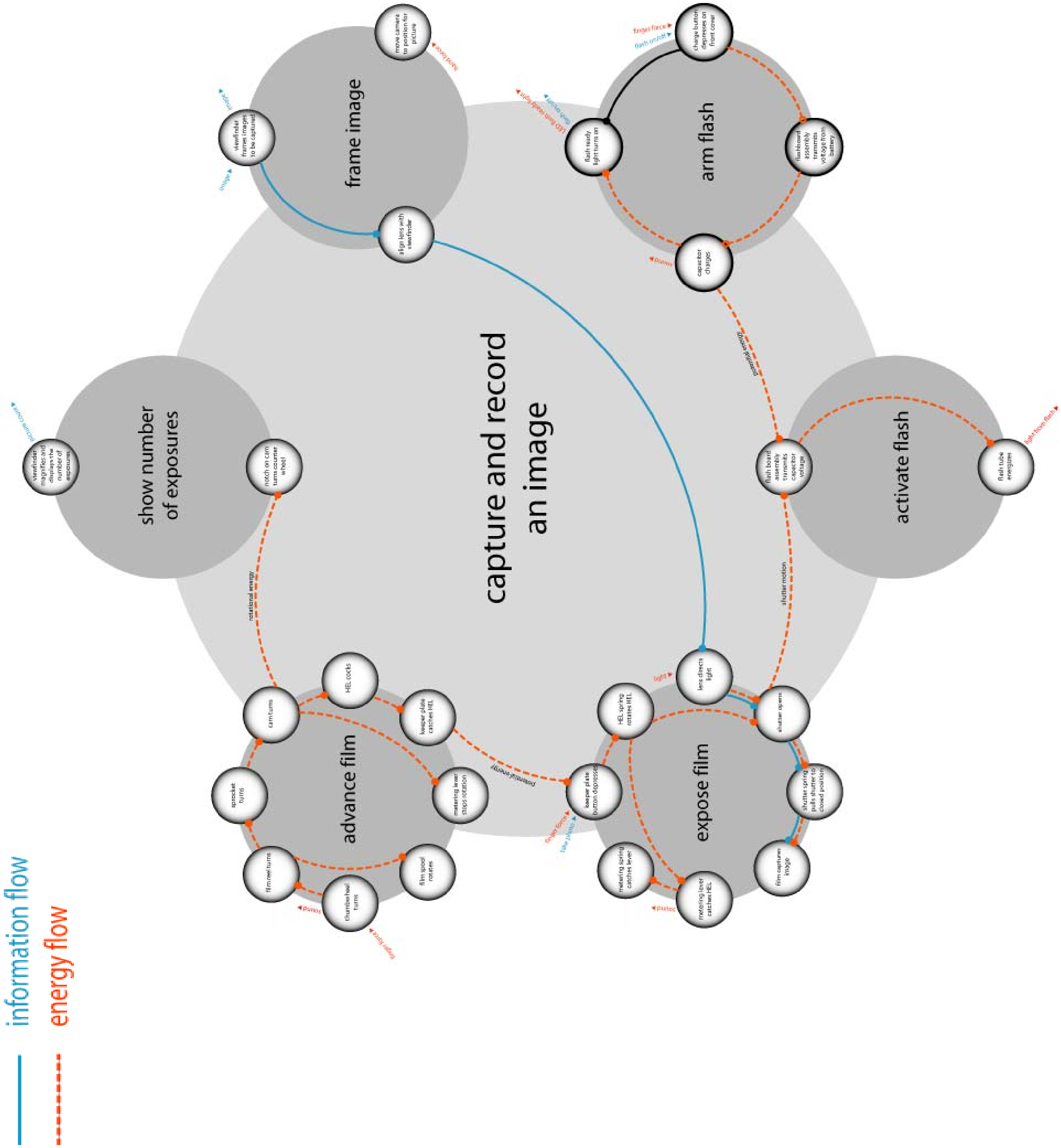


Figure 33: Third Level of Kodak Example of New Graphical Tool

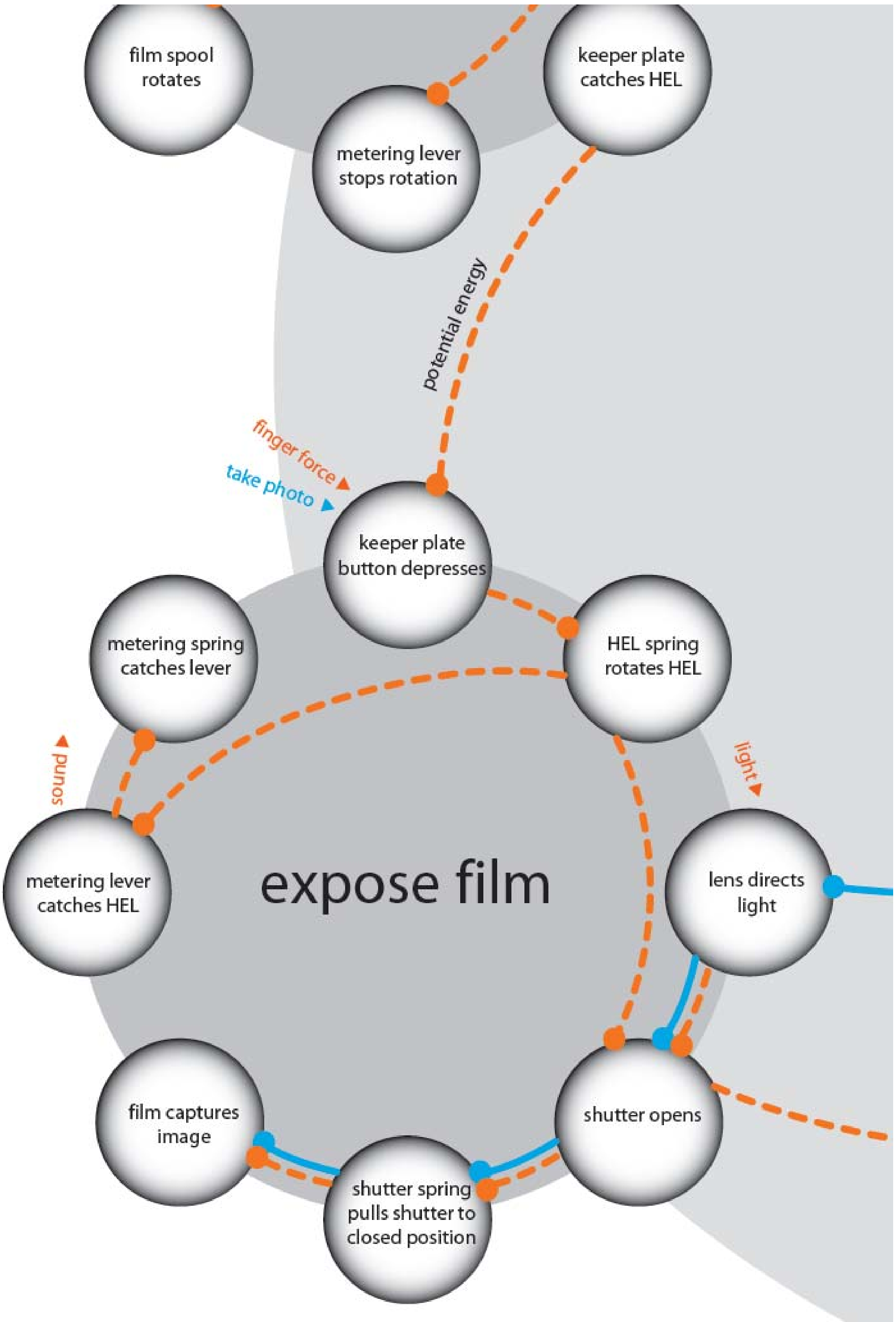


Figure 34: Zoomed in Third Level of Kodak Example of New Graphical Tool

CHAPTER 5: CONCLUSIONS AND FUTURE WORK

Through this research, a visualization tool has been successfully developed that can not only be used for the analysis of current products, but can be used to design new products as well. The design tool has been developed based on the need for an easy-to-use visualization tool, and its capabilities are based off the benefits and drawbacks of current design methods. Overall, the design tool is an effective communication technique between engineering and design because of its simplicity. The design tool has the ability for the user to 'design for…' many different criteria. The software design tool will help designers create new products and product families more efficiently in cost and time, thus leading to greater productivity, and more logical, sustainable designs.

There are several next steps progressing forward with this research. Another product should be analyzed using the current method and adjustments made to the design tool if necessary. Also, more in-depth research should be performed on how the design tool is beneficial for industrial designers as well as engineers and for all the 'design for…' criteria. A large next step includes the development and coding of the actual software tool that has an easy user interface. After completion, there would be consumer testing with designers, and the design tool will be refined. After successful completion of a refined software tool, the design method can be integrated into academics and industry.

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APPENDIX

KODAK CAMERA COMPONENTS AND THEIR FUNCTIONS

<u>FRAME:</u>

Front View

1. Connects to front and back cover, defines casing shape.
2. Notch for high energy lever. Defines plane for HEL to sit within.
3. Presses against outer cover for stability, possibly for machining.
4. Shelf for film casing stability.
5. Defines position of grey piece with button.
6. Defines the plane of the viewfinder, must be able to duplicate the view that will appear on the photo. Space provides no obstructions for view through the viewfinder.
7. Provides a latching piece for the clear viewfinder piece.
8. Provides support for clear viewfinder piece.
9. Support for grey button piece and vertical positioning above the grey winder and white numbered gear. It allows the gears to rotate without the grey button piece obstructing the motion.
10. Hook support for the grey button piece and defines vertical position above white numbered gear.
11. Vertical positioning that allows for rotation of certain pieces. Allows for movement of spring, two grey pieces, rotation the white number gear, and positioning of the grey piece with the button.
12. Piece restricts the motion of a grey piece with the gear. Defines how far the grey piece goes which defines the speed of the shutter. Top allows the rotation of the other grey piece.
13. Defines size and shape of grey winder. Allows for rotation of grey winder. Defines where unexposed film begins from.
14. Hole defines spatially how grey swirl piece rotates with film advancement grey gear. Provides support for both pieces. Hole defines spatially how grey swirl piece interacts with other pieces to open the shutter.
15. Path for grey piece to open and close the shutter.
16. Restricts motion of the grey piece to open and close the shutter. Stop/start point.
17. Notch provides axis of rotation for shutter. Provides support for black piece that holds lens.
18. Notch provides support for black piece that holds lens. Positions black piece that holds lens over the shutter.
19. Provides path of motion for the shutter.
20. Notch holds piece on circuit.
21. Space and notches provide location of capacitor within the circuit.
22. Support for circuit board. Defines positioning of circuit board. Provides positioning for the flash. Provides the support to connect the circuit board to the battery and defines their spatial locations.
23. Notches add stability to the circuit board and keep it in position around the cylinder.
24. Notch snaps circuit into position. Keeps the positioning between the notch on the circuit that holds the spring and number 17 constant.
25. Spacing provides holes for circuitry to exist.


Frame: Front View
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Back View

1. Connects to front and back cover, defines casing shape.
2. Notch connects frame to front cover.
3. Defines the plane of the viewfinder. Notch for placement of viewfinder.
4. Notch for flash ready light to be seen. Lines up with circuit. Provides the line of light.
5. Support notch for clear viewfinder piece.
6. Hole for film advancement gear. Defines spatially how grey swirl piece rotates with film advancement gear. Defines the location of the path where film is advanced.
7. Light trap so film does not get exposed unintentionally.
8. Hole allows grey winder to rotate unexposed film and advance.
9. Space provides positioning for unexposed film.
10. Notches frame image.
11. Positioning for film advancement. Provides a path for film to move smoothly it moves because of grey winding gear. Defines distance between lens with open shutter and advancing film.
12. Space provides positioning for exposed film to wind with black winding piece.
13. Notch allows for rotation of black rotating piece so as film advances it rotates.
14. Space provides positioning of battery.
15. Notches support capacitor.

FRONT COVER:

Outside View

1. Defines location of flash. Provides pathway for flash to reach outside camera.
2. Defines location of viewfinder. Provides pathway for viewer to see what the picture will be taken off.
3. Flash button provides a user interface to connect the button to the circuit board. Visual and sensory cues.
4. Visual/sensory cues for flash. No mechanical purpose.
5. Label provides color and design to show Kodak product.
6. Provides pathway for picture to be taken. Defines what the picture will be taken of.
7. Ridges frame picture.
8. 'Kodak film inside' provides product definition/advertising. No mechanical purpose.
9. Provides placement space for the lens and lens retainer. Gives more visual cue of a camera.
10. provides grips for user to hold onto camera. Raised height for better clearance with unexposed film part of frame

Inside View

1. Connects front cover to back cover.
2. Connects front cover to back cover.
3. Connects front cover to back cover.
4. Connects front cover to frame. (little notch connects too).
5. Clearance holes for flash board assembly.
6. Slit provides the ability of movement for the flash button.
7. X shape touches the flash board assembly and charges the capacitor.
8. Manufacturing circle.
9. Provides a frame for the viewfinder.
10. Machining process holes.
11. Machining process to make the KODAK on the front cover.
12. Manufacturing marks.
13. Provides a frame for the lens and provides support for the lens retainer and contact.
14. Manufacturing hole.
15. Provide support for capacitor. Defines placement against cover.
16. Back cover slides in here.
17. Provides a frame for flash.

BACK COVER

Outside View

1. Provides pathway for user to view and put the correct placement of the camera to take the picture.
2. Flash ready light is a visual cue to the viewer that the flash is ready to go. Provides pathway to the user. Defines path of flash ready light.
3. Raised surface has no mechanical purpose. Visual cue.
4. Raised surface allows sprocket to turn without interference.
5. Back label is a visual cue on how to work the camera.
6. Hole allows user to turn the thumbwheel and advance the film. Hole defines the first action to in the pathway to advance the film.
7. Frame notches around the thumbwheel allow the user to turn the thumbwheel easier. No harsh/sharp edges.
8. Notch piece provides auditory cue for user. As the thumbwheel turns, the notch makes a grinding noise. When the film has been fully advanced, the thumbwheel can't move, and there is no noise.
9. Hole allows counter wheel to spin without interference.
10. Provides grips for user to hold onto camera. Raised height for better clearance with unexposed film part of frame

Inside View

1. Effect of machining to produce visual cue on the outside of the back cover.
2. Clip snaps onto frame. Holds frame steady, does not allow light to pass through the light trap because it's snapped in.
3. Light trap
4. Manufacturing circle.
5. Raised surface allows sprocket to turn without interference.
6. Raised surface allows film to advance and stay within boundaries of light trap
7. Lines provide the path for the film to advance
8. Notch connects to frame.
9. completes the light trap and completes the circle for the spool to turn. Defines the placement of the spool.
10. Small notch provides room for exposed film to wind.
11. Slot completes the light trap and holds the frame in place. Vertical holder for the battery. Defines the space for the battery.
12. Connect back cover to front cover.
13. Support for battery.
14. Manufacturing.
15. Provides connectors to the frame to hold in exact spot.

FRONT COVER, BACK COVER, AND FRAME CONNECTING VIEWS (FUNCTIONS FOR FRAME)

Top View

1. Snap connector to front and back frame.
2. Hole for viewfinder piece to show the number of pictures left. Visual cue.
3. Slot to slide into front frame.
4. Hole for button on keeper plate to be pushed. Force from user that affects the picture taking begins here.
5. Connector knobs with corresponding holes.

Bottom View

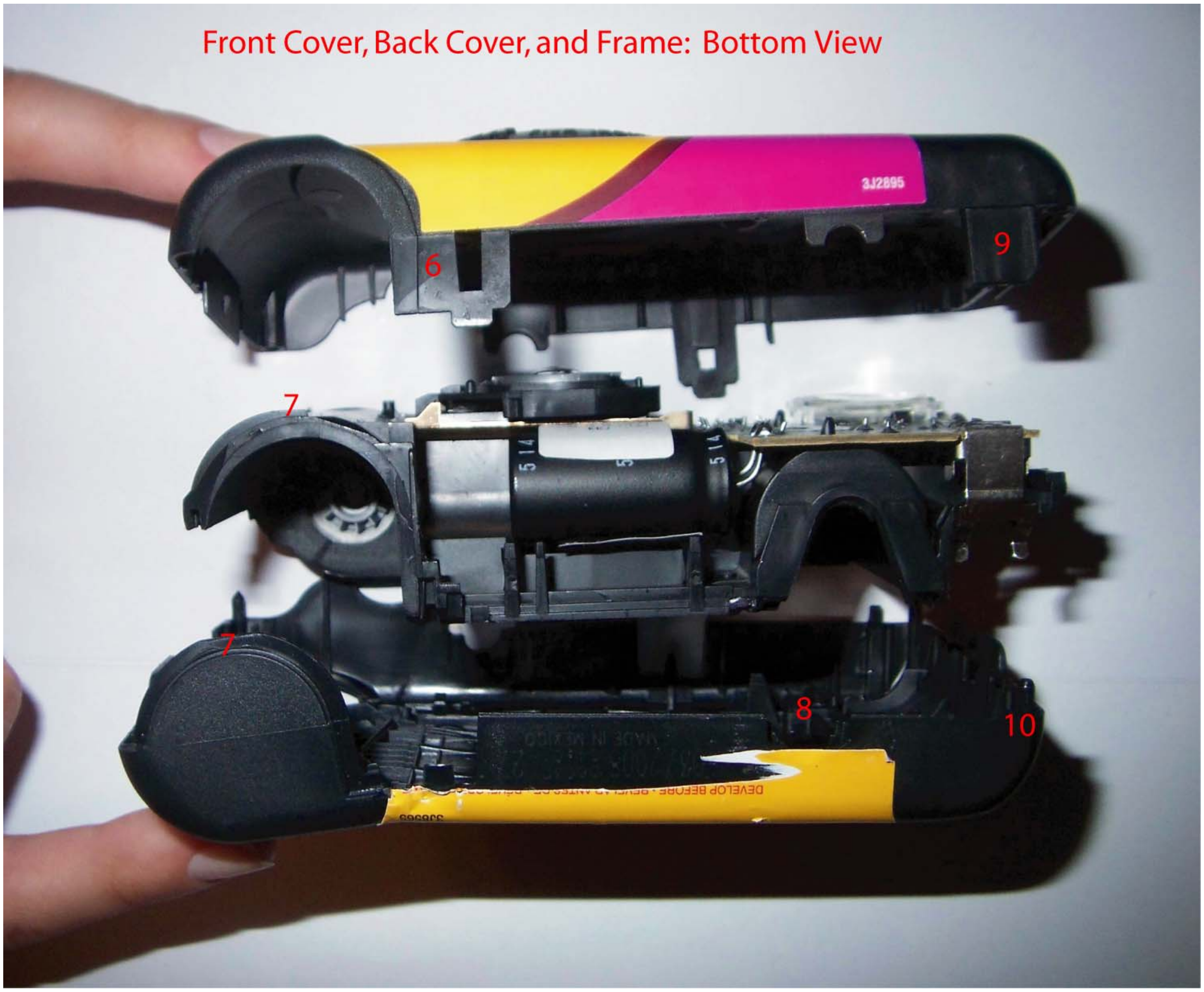
6. Snap connector to front and back frame.
7. Slides in to complete part of the light trap.
8. Placement and shape allows rotation of spool.
9. Connector to front and back frame. Supports flash board assembly and battery.
10. Connector knob with corresponding hole.

Left Side

11. Snap connector to front and back frame.
12. Part of light trap.

Right Side

13. Snap connector to front and back frame.


Front Cover, Back Cover, and Frame: Bottom View
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Front Cover, Back Cover, and Frame: Side Views
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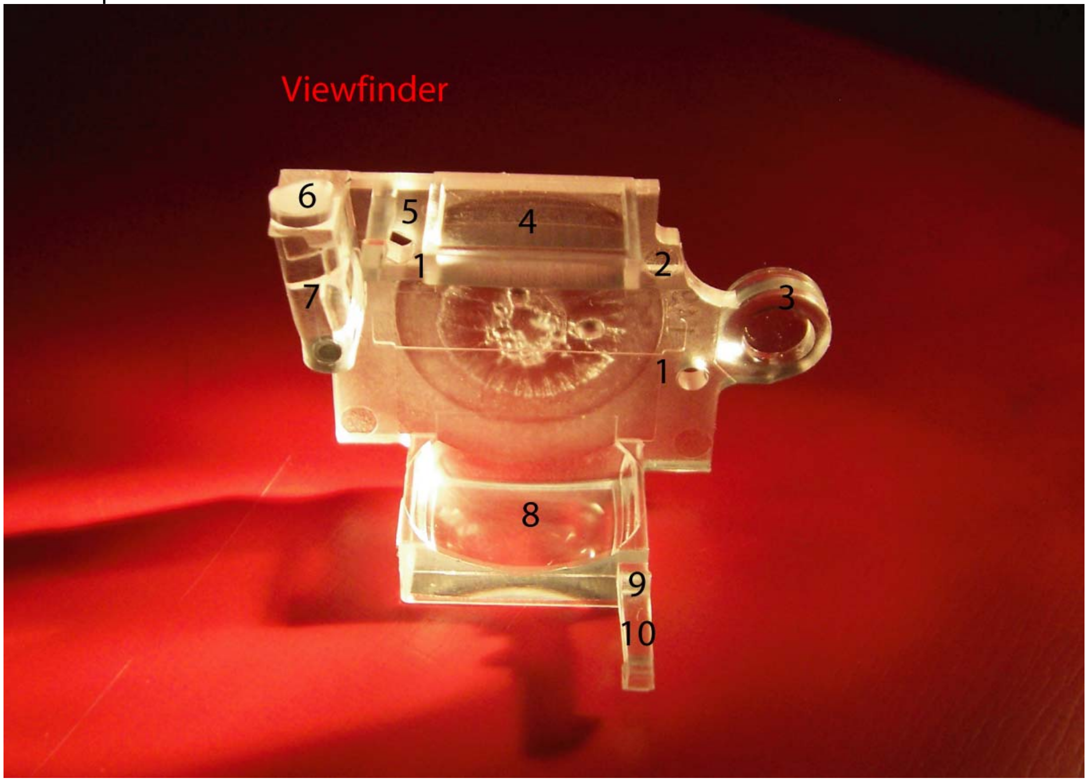
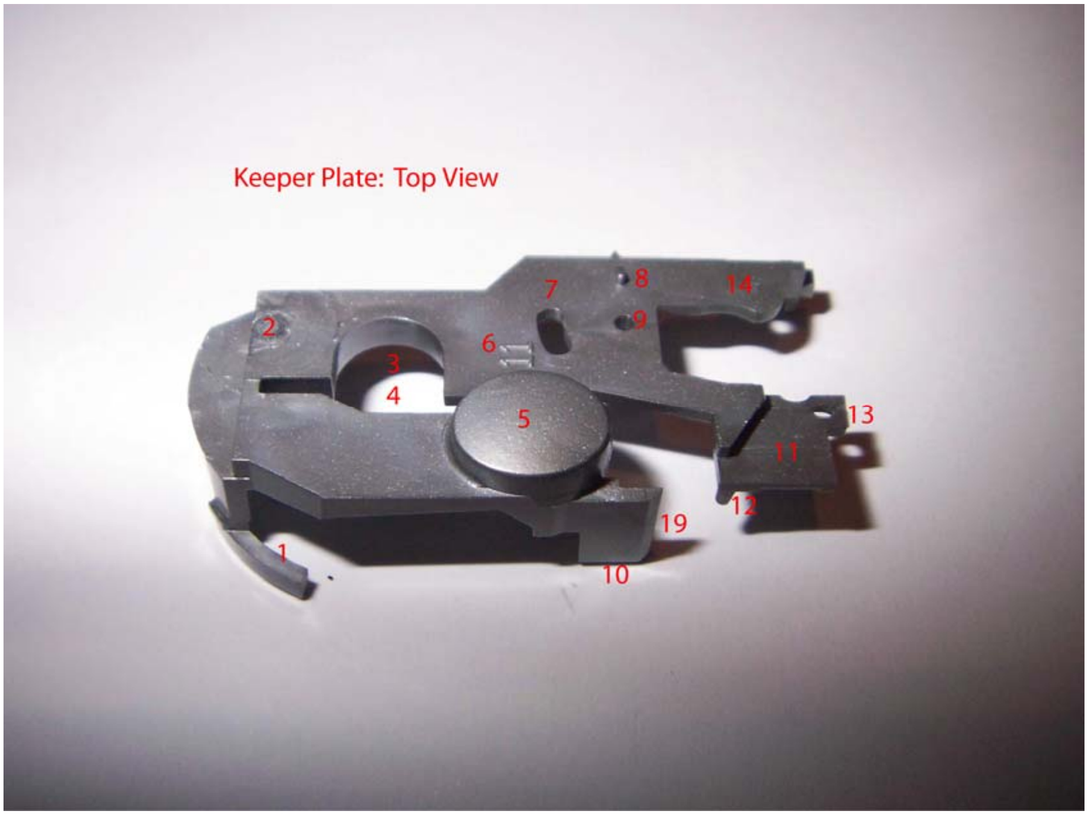
VIEWFINDER

1. Placement support holes on frame.
2. Shape curves around keeper plate.
3. Magnification gives visual cue to user to how many pictures are left. Defines the counter wheel location.
4. Visual cue of where the user is to look through the camera. Defines the plane of the viewfinder.
5. Snaps viewfinder into the frame.
6. Circle provides the path for the LED light out of the camera.
7. Plastic captures the light from the LED and sends it to number 7.
8. Allows the view to come out the other side of the camera. Lens shows how the picture will look if taken by the user. Curved shape correlates with the dimensions of the picture taken.
9. Manufacturing
10. Snaps viewfinder into frame.



KEEPER PLATE

1. Hook stabilizes keeper plate on frame.
2. Manufacturing
3. Hole allows for rotation of thumbwheel.
4. Slot allows keeper plate to deflect downward.
5. Button that is a visual cue for user to push to take picture. Where initial force is input to the camera.
6. Manufacturing
7. Manufacturing
8. Manufacturing
9. Hole fits over top of frame for stabilization. When button is pushed, the keeper plate won't run into the counter wheel. Keeps counter wheel in position if camera gets turned upside down.
10. Contact piece to HEL. Piece transfers user input force to HEL. Shape is specific so that when button is pushed down, it allows the HEL to move through a line of motion where the piece used to be.
11. Dropdown of plane to allow keeper plate to rest on frame.
12. Protrusion keeps metering lever in the correct plane when the camera is being moved around.
13. Hole stabilizes keeper plate on a protrusion of the frame.
14. Hole stabilizes keeper plate on a protrusion of the frame.
15. Hook protrusion inserts into hole on frame to stabilize keeper plate.
16. Protrusion keeps the thumbwheel in the correct plane when the camera is being moved around.
17. Hook snaps into frame to stabilize keeper plate.
18. Other protrusions and circles are for manufacturing (on bottom side).
19. Sloped surface provides path for HEL


Keeper Plate: Top View
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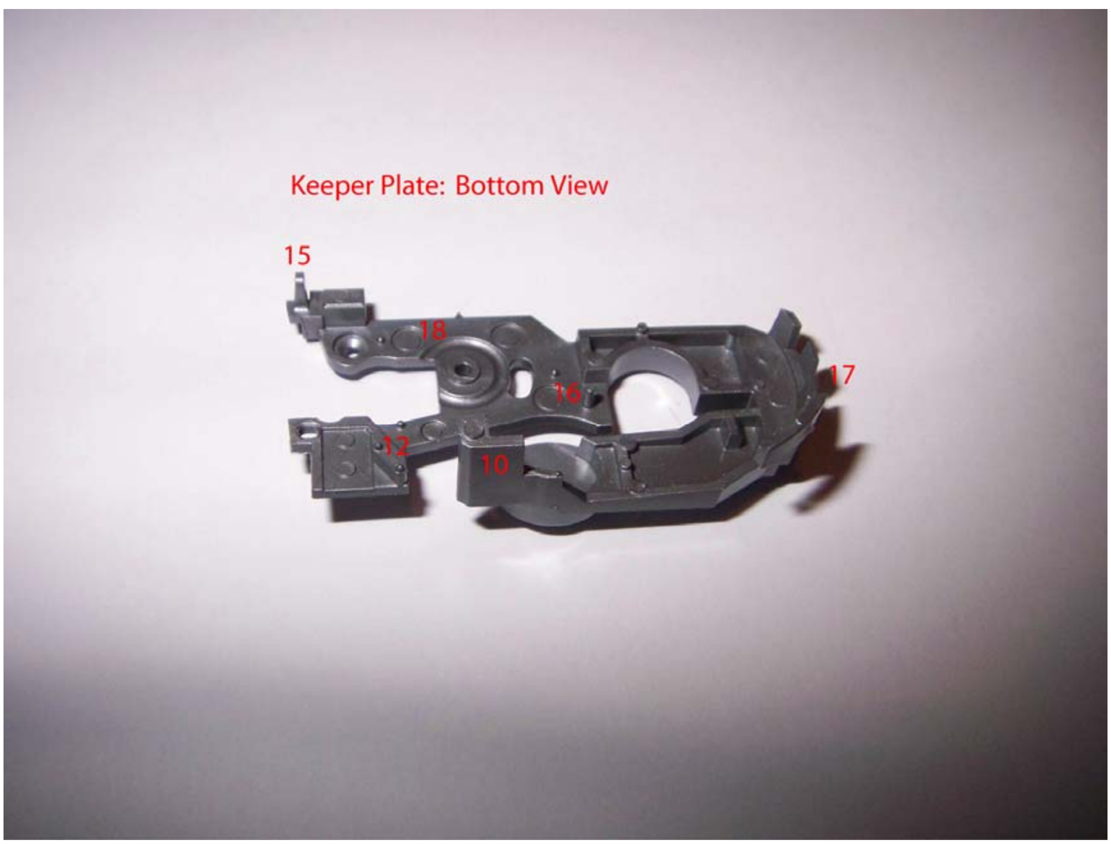
Keeper Plate: Bottom View
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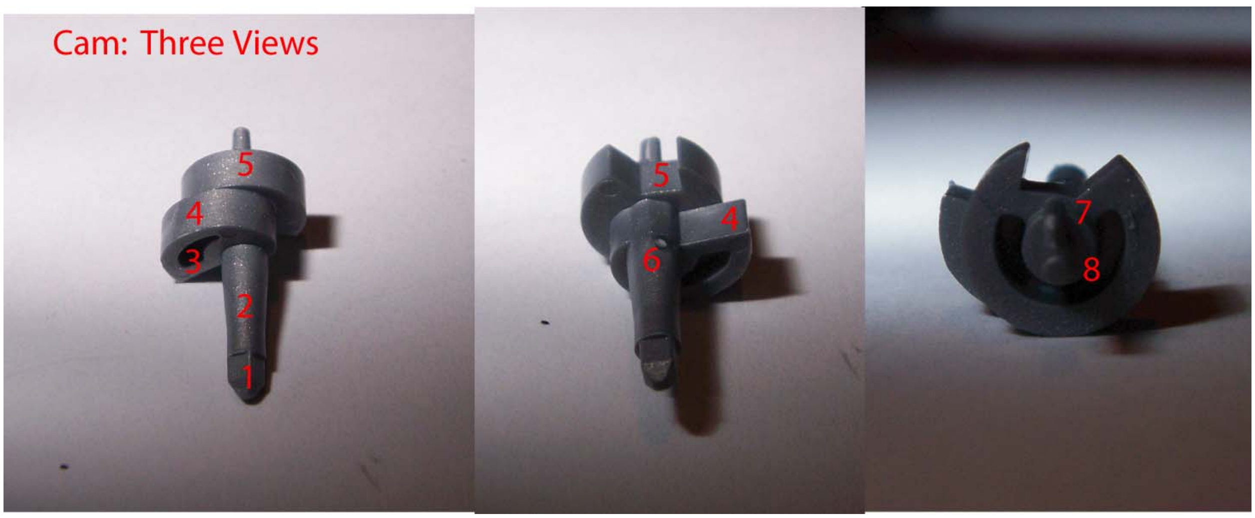
COUNTER WHEEL

1. Manufacturing hole.
2. Hole to maintain plane on which the counter wheel turns. Hole is stabilized on frame.
3. Numbers show visual cues of how many pictures are left.
4. Gear teeth turned by cam allow rotations of numbers.
5. Manufacturing.

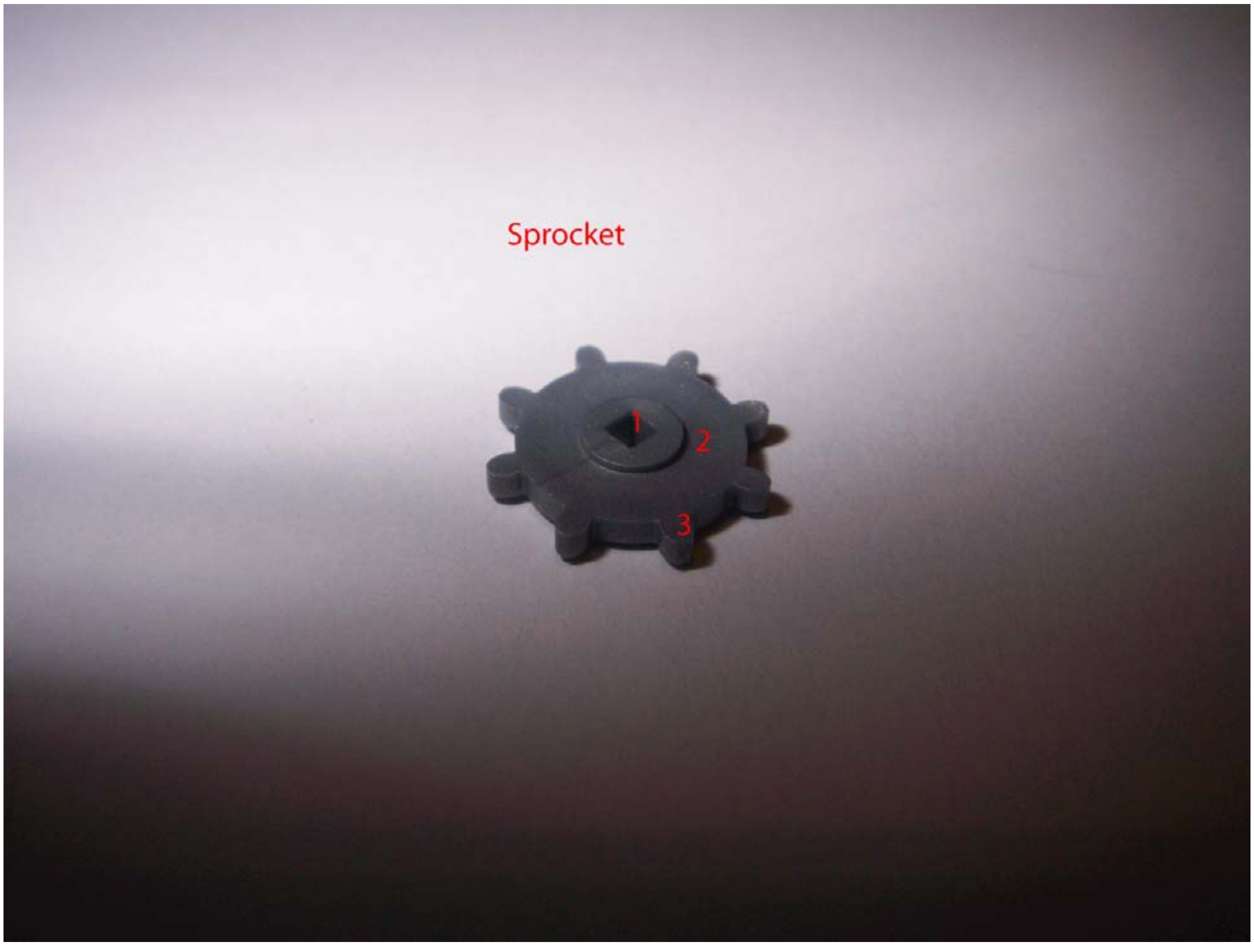
CAM

1. Connects to sprocket and creates rotation of cam as the film advances.
2. Protrusion connects top part of cam to part connecting to sprocket. Defines the plane in which the sprocket and cam system rotate.
3. Manufacturing hole.
4. Lower half circle with notch rotates as the HEL moves. This in turn rotates the sprocket.
5. After HEL moves, the cam rotates and the second half circle notch system causes metering lever to move.
6. Manufacturing.
7. Notch rotates counter wheel teeth.
8. Protrusion provides support to the keeper plate.



SPROCKET

1. Square hole attaches to the protrusion from the cam and rotates from the cam.
2. Protrusion allows the sprocket to have clearance in the slot of the frame.
3. Gear teeth are used to advance the film as the sprocket rotates.

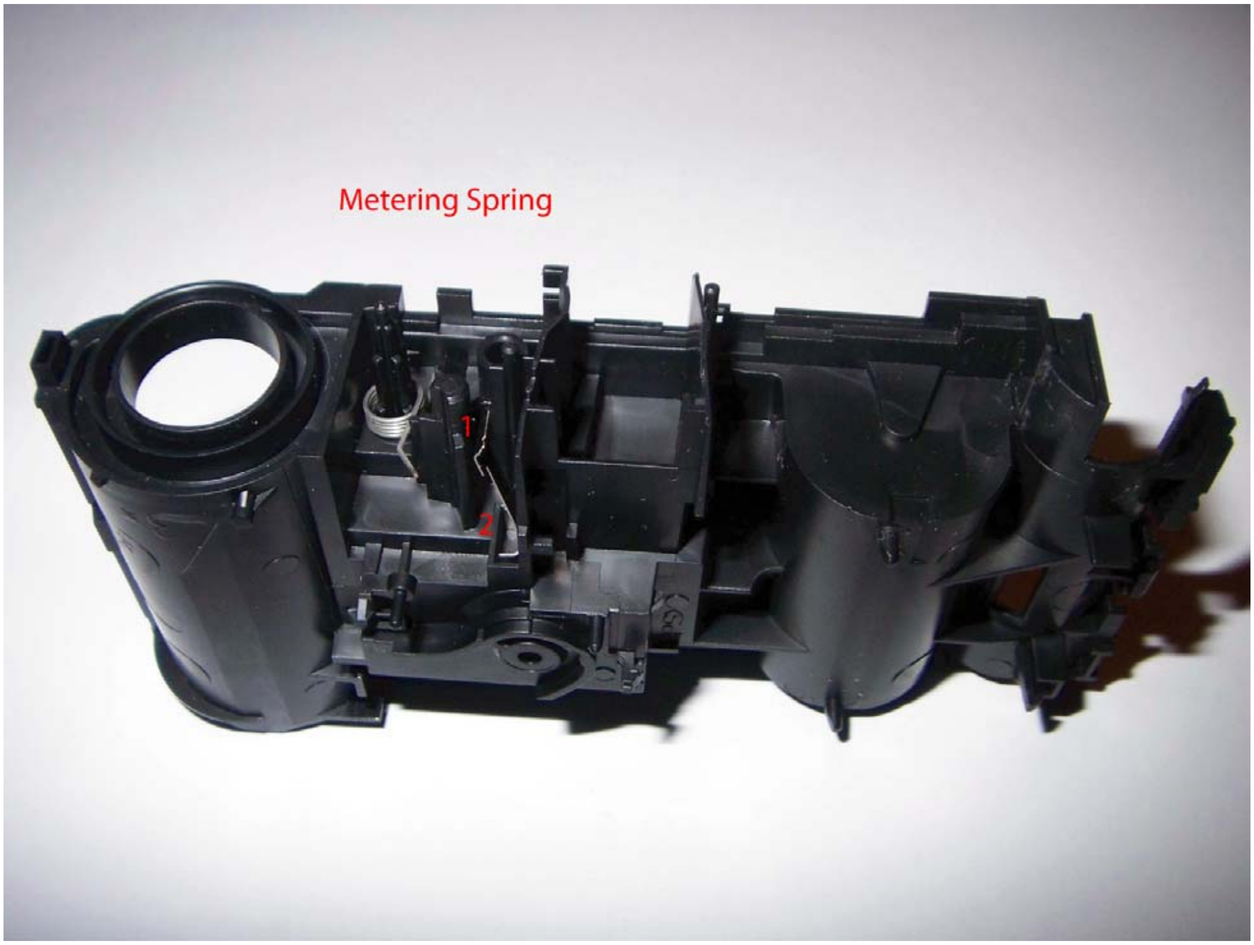


THUMBWHEEL

1. Manufacturing.
2. Protrusion keeps level plane with keeper plate when camera is being moved around by the user.
3. Gear teeth are for a auditory cue to the user to indicate that the film is being wound, and provides traction for the user to wind the thumbwheel.
4. Inserts into the unexposed film and advances the film.
5. Rests on frame and defines the plane of rotation.

METERING SPRING

1. Contact point for metering lever. Defines plane of motion for metering lever.
2. Contact with frame, attaches here.



METERING LEVER

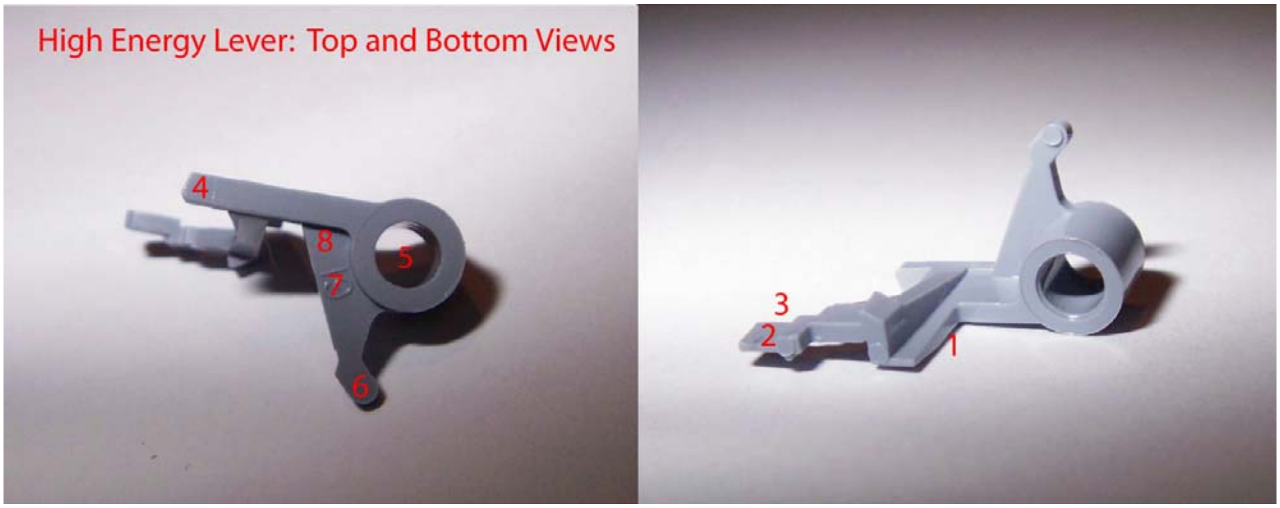
1. Notch provides contact with cam (prevents film from being exposed twice)
2. Hole defines plane of metering lever.
3. Manufacturing notch.
4. Ridge for manufacturing.
5. Contact point with metering spring.
6. Contact with HEL. Causes motion of metering lever.
7. Notch contacts thumbwheel. Prevents shutter from being prematurely pressed.
8. Manufacturing notch.
9. Manufacturing marks.

HEL SPRING

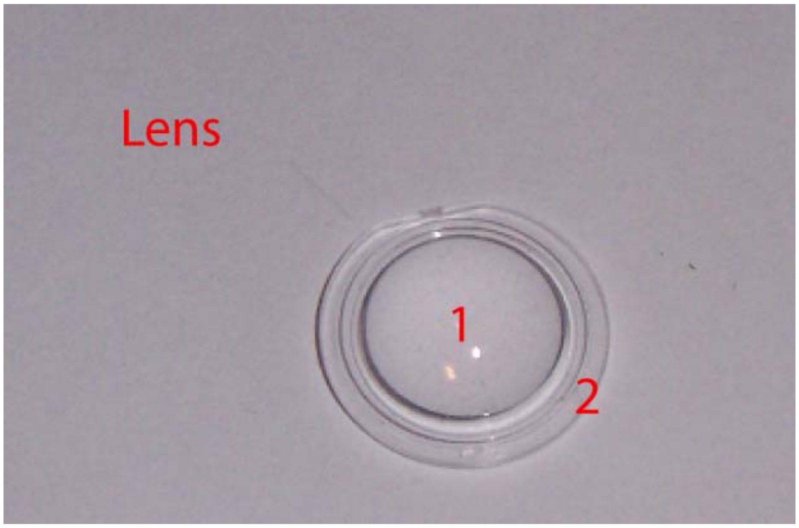
1. Provides spring force to HEL. Defines speed and plane of motion of HEL and speed of shutter.
2. Connects to frame for stability.
3. Number of spirals also defines speed of HEL and provides stability.
4. Circular spring defines location of HEL spring.

<u>HEL</u>

1. Provides contact to HEL Spring. Part that begins motion for the HEL when button is pressed.
2. Contact with shutter. Causes shutter to open and close. Defines speed of opening and closing of the shutter.
3. Notch fits under lens retainer to keep the plane of motion consistent to open and close the shutter.
4. Moves over keeper plate so when the user presses the button, the HEL is released and the shutter opens to take the picture.
5. Hole defines the position of the HEL and its axis of rotation.
6. Contact with the cam which rotates the film in the correct position so the film isn't exposed twice.
7. Manufacturing number.
8. Manufacturing lower notch.



LENS
1. Lens allows picture to be taken with the correct size/shape when the shutter is open.
2. Flat ring stabilizes the lens when in contact with the lens retainer and contact.



CONTACT
1. Manufacturing.
2. Hole defines plane of lens.
3. Notch connects contact to lens retainer and stabilizes lens/contact system.
4. Outer circle is thicker to keep lens in place.

LENS RETAINER

1. Hole provides pathway from film to lens.
2. Flat part defines the plane of the lens.
3. Raised part stabilizes the lens when the camera is being moved about.
4. Notches hook in the contact to stabilize the lens.
5. Flat part allows the contact to be rotated and set in place during manufacturing.
6. Manufacturing.
7. Manufacturing.
8. Hole allows protrusion from the frame to stabilize lens retainer. Keeps shutter in its place when camera is being moved about. (same protrusion the shutter rotates about)
9. Hole allows protrusion from the frame to stabilize lens retainer and keep shutter in place when the camera is being moved about.
10. Manufacturing.
11. Notch hooks into frame of camera to stabilize the lens retainer and keep shutter in place when the camera is being moved about.
12. Hole allows notch from 11 to move into the plane of the lens retainer.
13. Manufacturing protrusion.
14. Bar moves over part of the frame and hooks into the frame. Stabilizes the lens retainer and the shutter.
15. Bar maintains the plane of flow for the HEL opening the shutter.
16. Manufacturing.
17. Flat plane allows for motion of the shutter.


Lens Retainer: Top View
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Lens Retainer: Bottom View
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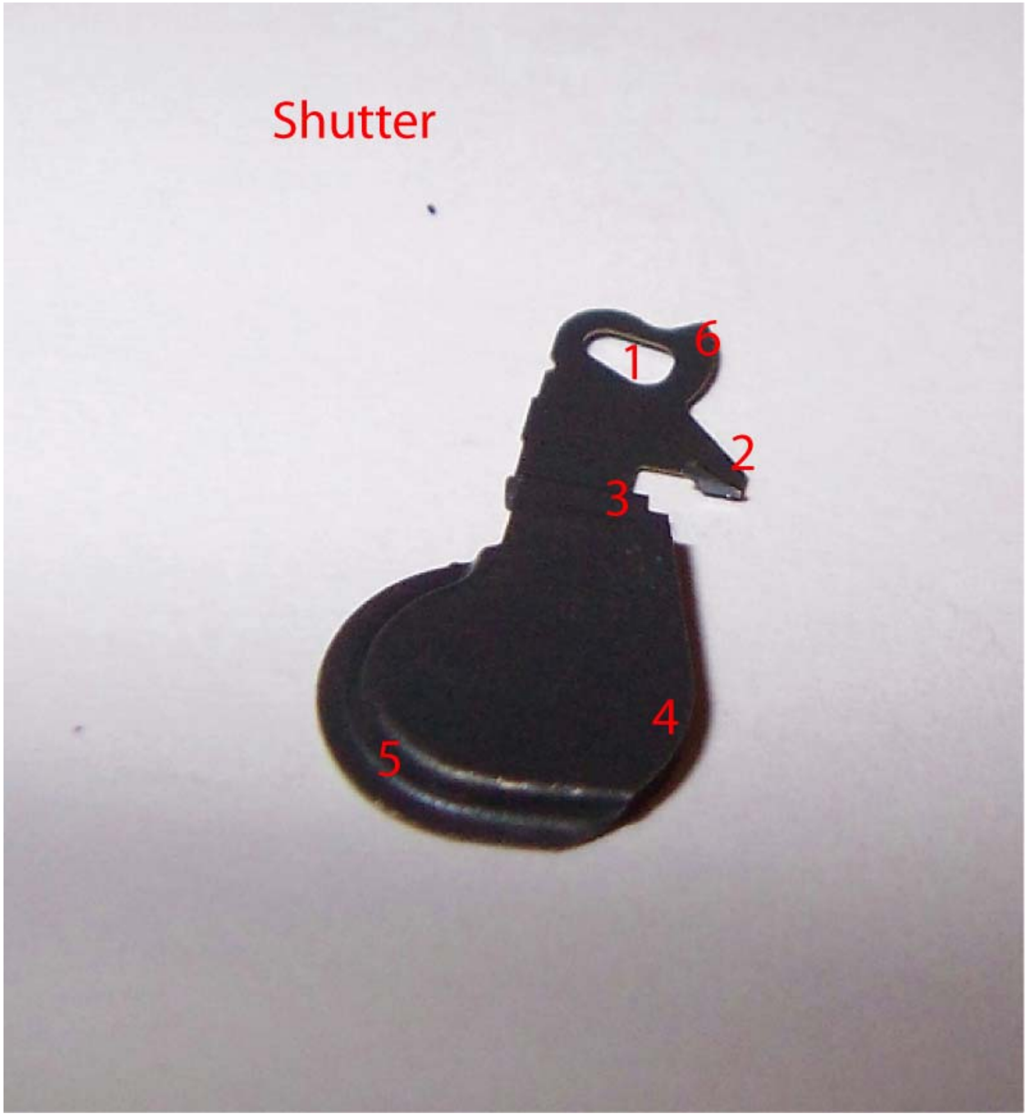
SHUTTER

1. Hole allows frame protrusion to create an axis of rotation for the shutter. Two pivots on the shutter allow HEL to move over the shutter without exposing.
2. Notch hooks on the shutter spring. Part of the path to complete the circuit.
3. Notch defines the plane of the frame in which the shutter can rotate about.
4. Keeps the film unexposed until the user takes the picture.
5. Notch completes part of the path of the circuit by hitting the metal bar. Also, notch helps to define pathway from the frame to the shutter.
6. Raised part allows for contact with the HEL which opens the shutter. This begins the motion of the shutter.



SHUTTER SPRING

1. Connects to notch of the shutter.
2. Connects to notch on circuit board.
3. Pathway between the shutter and circuit board. Expands as the HEL opens the shutter, and spring properties cause the shutter to return to its initial state. Spring determines the time that the shutter takes the close.

SPOOL

1. Film is wound around notch in spool. Film starts on notch.
2. Injection molding creates the thin walls and ribs and notches.
3. Diameter of spool determines how much film can be wound around it within the space constraints.
4. Length is comparable to the size of film.
5. Spool in general defines the path of the film.
6. Notch on top fits into grove on frame. One part of defining the axis of rotation of the spool.
7. Notch on bottom fits into grove on frame. Other part of defining the axis of rotation of the spool. Notch also is part of keeping the light out so the film does not get exposed.
8. Top and bottom of spool keep the film in the correct linear position so film does not get caught in the top or bottom of the spool.
9. Manufacturing.

FLASH BOARD ASSEMBLY

1. Holds the shutter spring in place. Part of completing the circuit.
2. When the shutter strikes here, the circuit is complete and the flash takes at the appropriate time when the shutter is open.
3. Connects to frame for stability.
4. Provides contact with battery.
5. Connects to frame for stability.